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Science and the film

In this number we publish an article based on a film recently taken at a London hospital. This film marks a notable step forward in the application of cinematography to the needs of science. It records the movements of the tongue in human speech, and is the first record of such movements by the film camera. The film is therefore important, not only as a matter of scientific interest, but as of direct assistance to speech therapy. It has been welcomed particularly by the Royal Air Force as a contribution towards the rehabilitation of flying men with facial injuries who have virtually to be taught to speak again.

There is still a tendency in scientific circles to regard the film as a method of public entertainment, and thence to assume that films other than those of a dramatic character are not tolerated unless served up in a manner which demands no conscious mental effort and therefore leaves no worth-while impression. If such an assumption is true, it represents one of the defects of modern culture which science is concerned to remedy. It is a call for action. It is, however, doubtful if the generalization is entirely correct. There is abundant evidence that a proportion of the cinema-going public, though perhaps not a very large proportion, does welcome the informative type of film; and that the more intelligent cinema owners recognize the need to include in their programmes a percentage of films which 'appeal to the intelligence instead of assault the emotions.' Unfortunately, through the activity of the publicity man, this type of film has tended to become suspect. It has too often been made a camouflage vehicle for propaganda or advertisement. Yet the success of documentary films such as the world-famous British 'Secrets of Nature' should leave no doubt that an important place might and ought to be found, even in public entertainment, for informative or instructional films. The trouble is that no serious attempt has yet been made to produce scientific films in sufficient quantity, or simple and attractive enough to be understood without undue effort by members of the general public.

Realization that the film is a powerful agent for the exposition of science has quickened only within the last few years. It has received a great stimulus during the war, when there has been need to warn or instruct the services or the public on points of tactics, safety, and well-being. A most encouraging sign is the way in which scientific film associations have bred and mustered. In Great Britain there are today nearly 100 such associations, and these have recently come together in a single national association. The value of such a society is not least in the inducement it offers to those willing to sponsor scientific films. It gives them assurance that the films they make will be seen by large audiences of persons with greater intelligence than the average likely to be found in the entertainment theatre. As to what constitutes a 'scientific' film, we may subscribe to the generously framed definition which describes as scientific 'any film which (*a*) presents phenomena or events objectively for observation or study; (*b*) investigates, presents or explains phenomena or events in a way which shows them to be part of a rational coherent whole; and (*c*) shows that such investigation, presentation, or explanation as a method of looking at reality can be used by anyone and can enable him to live more fully.'

It was once remarked by an able lecturer that the secret of success in lecturing was to assume that the audience had no previous knowledge of the subject. Something of the same assumption is necessary if scientific films are to be successfully devised for audiences of the general public. The quantity of information offered must be prudently regulated, and it cannot be too often reiterated that there is only room for one single message in

each film. Provided that this one message is assimilated by a reasonably large proportion of the audience, the film can be regarded as a success. A difficulty is that scientific men who interest themselves in film production may fail to recognize the extent to which scientific terms and images are foreign to the minds of the ordinary citizen. It should be emphasized that it is not sufficient to make the ordinary man and woman appreciate that science 'can do something' for them. There is the larger object of familiarizing the community with scientific methods and of imbuing it with the spirit of science. The film, more rapidly and surely than almost any other vehicle, could help to achieve this aim if used with imagination and insight. Perhaps it will have less direct effect upon the older generation, whose minds are already past the stage of receptivity, but the future is with the young, and there is no doubt of the power of the film to open the doors to a new world for children and adolescents. Even with the young generation, however, there are problems. We know with increasing precision what can and what cannot be done with pedagogic films, and there is every indication that educational organizations are alive to the great possibilities which await the film for teaching purposes after the war. Enthusiasm, however, may become uncritical, a danger that is perhaps more likely to affect scientific than other subjects which the film may be used to teach. Science teachers will have to face the responsibility of deciding what type of films they require, and this is not a matter which can be settled out of hand. It will need the production of preliminary experimental films, designed by science teachers in collaboration with film technicians, and followed by educational research, in which the films are tested in a variety of schools and by a variety of methods. Until a fairly extensive scheme of research along these lines has been carried out, those charged with the duty of teaching science to children would seem well advised to adopt a cautious attitude towards the spate of films that may be expected on the return of peace. Quite apart from this, there will be the need to train teachers in the appropriate technique—psychological as well as manipulative.

In colleges and universities the film will be valuable in research as well as in education. Records of natural processes, such as the speech therapy film already referred to, and of experimental demonstrations, constitute an excellent method of putting students into close touch with the realities of their subject and of keeping them abreast of developments as they occur. The film can also serve to demonstrate laboratory experiments on an industrial scale, and thus to stimulate the student's interest by showing him that work which may seem to him purely academic, or even dull, has a definite and practical application in the realm of production.

In research, the film has already well proved its worth, particularly in the study of the dynamics of living matter. As a permanently recording medium, it enables transient phenomena to be studied and analysed without haste; and by accelerating or retarding the record fuller comprehension of a continuous process is often obtainable than could be derived in any other way. Among the problems successfully investigated by cinematography or cinematomicrophotography are the course of the circulating blood in the living foetus within the mother, and the fertilization and early development of the living mammalian ovum *in vitro*. It is fitting that the film should be so efficient a servant of biology, for, as Dr Pijper has recently recalled, filming had its origin in biological curiosity: the desire to know whether a galloping horse ever has all four feet off the ground at the same time. This was in 1872, when the American Muybridge made a galloping horse photograph itself in a succession of twenty-four cameras by means of wires stretched to the shutters. In this work there were the 'two elements that make a film: analysis by a rapid succession of photographic pictures, and a suitable synthesis of the pictures on a screen.'

One thing is certain—that the encouragement of the film is of great direct, and of greater indirect, importance to science. At the moment and in most countries the production of films by private individuals or undertakings is necessarily subject to extreme limitations; but it is not too soon to examine the problem. Exploratory work carried out now will facilitate production when peace returns to the world.

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.R.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

Climate, weather, and man

DAVID BRUNT

Is it by chance that the early civilizations arose on or near the isotherm of annual mean temperature 70° F? Is it significant that the glories of the Tudor period in England came so soon after the general use of coal for heating? Professor Brunt has interesting suggestions to make on these and other questions, and indicates also that the white man's reactions to hot climates promise to be important in post-war settlement and therefore deserve close study.

SOME REACTIONS OF THE HUMAN BODY TO ATMOSPHERIC CONDITIONS

The human body works best when its internal temperature is about 98° F, and any marked deviation from this temperature leads to discomfort, and in extreme cases to death. Heat is produced within the body by the process of digestion and by muscular effort, and must be dissipated from the body as fast as it is generated, if equilibrium of body temperature is to be maintained. The body can, however, maintain approximate equilibrium under a wide variety of external conditions, and a man shivering with cold on a winter's day will have almost the same internal body temperature as on a summer day with the sweat dripping from his forehead.

The heat generated within the body is conducted to the skin, largely by the blood circulation, and is dissipated from the skin by radiation, convective air motion, and the evaporation of perspiration. In a cold environment the surface blood-vessels contract, so that the conduction of heat to the skin is checked, while the loss of heat from the skin to the environment is to some extent minimized by the cooling of the skin. At a certain stage of body cooling there is an onset of shivering, which is an attempt to increase heat-production by muscular movement. Gooseflesh, an involuntary raising of the hairs on the body, each by a tiny muscle, is an effort to retain as deep a layer as possible of warm air in contact with the skin. At low temperatures, the internal generation of heat in the body is accelerated by the discharge of fluids from the thyroid and adrenal glands into the blood-stream.

In a hot environment, or during physical effort, a new mode of heat regulation comes into operation. The sweat-glands become active and discharge water on to the surface of the skin, from which it evaporates, and in so doing removes heat from the skin. As the temperature of the environment rises, the rate of sweating increases, until a stage is reached at which sweat drips from the body. If the body temperature continues to rise, in spite of the loss of heat by the evaporation of sweat, the blood-pressure falls, the pulse-rate increases, and strong palpitation is felt, followed by a condition of stupor which ends in death by heat-stroke.

In a clothed man reclining indoors, the sweat-glands do not become active until the temperature of the environment has reached about 29° C (84° F). At temperatures below this limit there is an insensible loss of water, as vapour, through the skin and from the walls of the lungs. The cutaneous insensible perspiration does not pass through the sweat-glands, except on the palms of the hands and the soles of the feet; it does not wet the skin. It varies considerably in different persons, and is usually stated to be from $\frac{1}{30}$ to $\frac{1}{18}$ pint per hour, or about $\frac{3}{4}$ to $1\frac{1}{2}$ pints per day. The active secretion of sweat is at a much higher rate, and may be as much as 9 pints per hour during an energetic game of football.

The temperature of the skin varies over different parts of the body, and in a cold environment is lowest over the feet, next lowest over the hands, and highest over the head. The extremities are the coldest parts of the body, the trunk being less affected by low temperature of the environment. The wearing of sufficient clothing will maintain the skin temperature over the trunk at a high level, but the extremities require special protection in a cold environment. This emphasizes the need for care in the design of gloves and boots for men exposed to low temperatures.

THE HEAT ECONOMY OF THE BODY INDOORS

The processes of oxidation of body tissues, in the course of digestion or of physical effort, are grouped under the term *metabolism*, and the rate of

generation of heat in the body by these processes is known as the metabolic rate. There are three processes of removal of heat from the body. Heat will be carried by the air (by convection) to or from the body, according as the environment is warmer or colder than the skin. The body will gain or lose heat by radiation to and from surrounding objects, walls, etc., according as the radiating parts of the environment are warmer or colder than the skin. Further, heat is constantly being lost by the evaporation of perspiration from the skin and of water from the walls of the lungs. The body may suffer a net loss of heat and become cooler, or may suffer a net gain of heat and become warmer. The net rate of loss of heat from the body is called *storage*, and is treated as negative when the body heat-content increases.

The sum of the metabolic rate and the storage rate must be equal to the sum of the three rates of loss—by evaporation, by radiation, and by convection. The metabolic rate is measured by the oxygen–carbon dioxide exchange of the body. The rate of loss of heat by evaporation is deduced from the loss of weight of the body. The rate of storage is deduced from the change in the mean temperature of the body, the specific heat of the body being taken as 0·83. It is then possible to compute the rate of loss of heat by radiation and convection.

The experimental data referred to below were accumulated, in the course of a long series of experiments, at the John B. Pierce Laboratory of Hygiene, Newhaven, Conn., by the Director of the Laboratory (Dr C. E. A. Winslow), Dr L. P. Herrington, and Dr A. P. Gagge. The subjects of the experiments were placed in a specially constructed booth, in which temperature, humidity, and air movement could be controlled, while the radiation from the walls could be controlled by specially reflecting or heating devices in the walls. The balance used for weighing the subjects was sensitive to 2 grams, about $\frac{1}{14}$ oz.

As clothing is a complication which tends to mask the essential physiological processes involved, the earlier experiments were usually made on nude subjects, but later experiments were made with clothed subjects. The clothing worn consisted of a two-piece suit of cotton underwear, a cotton shirt without ties, socks, low leather shoes, and a grey suit with three-quarter lined coat and fully lined vest. The air movement was restricted to 17 ft. per minute.

A series of experiments on subjects so clothed, and reclining indoors, is summarized in figure 1. Here the unit in which the rates of exchange are given is 1 kg-cal. per square metre of skin surface per hour. The operative temperature which is plotted in the diagram is a weighted mean of the temperature of the air and walls, estimated to give a representation of the joint effect of radiation and convection, and it is only the sum of these two items which is shown in the diagram. The operative temperature is equal to the air temperature when the air and the effective radiating surfaces are at the same temperature.

The metabolic rate, as shown in figure 1, varies little with temperature, though there is a definite rise at the lowest temperatures. At all operative temperatures up to 29° C the evaporative loss is the combined effect of evaporation in the lungs and of the loss of insensible perspiration through the skin. At temperatures above 29° C the evaporative loss is mainly due to the evaporation of sweat discharged through the sweat-glands, and in a hot environment it is this evaporative loss which exercises the essential control over body-heat. At low air temperatures the essential control over heat loss is by the joint effect of radiation and convection, but at the highest temperatures shown in the diagram these two factors yield a small gain of heat by the body, a gain which can become important when the air movement is high. The curve for storage shows that in an environmental temperature below about 25·5° C the body loses heat, and cools. Thus we may define a zone of body cooling from 25·5° C downward, and a zone of evaporative control from 29° C upward. In the intermediate zone from 25·5° C to 29° C there is neither body cooling nor active secretion of sweat, and the equilibrium of the body is maintained by the control of the flow of heat from the inner parts of the body through the dilation or contraction of the surface blood-vessels. This intermediate zone is known as the zone of vasomotor control.

In figure 2 are shown, for nude subjects, values of the mean skin temperatures, of the wetted area of the skin, and of the conductance of the body for a similar range of temperatures to that of figure 1. In the zone of evaporative control the skin temperature is independent of operative temperature, except for a slight rise at operative temperatures above 37° C. At all temperatures below 31° C the skin temperature falls off by about 1° for every 2° fall of operative temperature.

W, as shown in the diagram, is a measure, in arbitrary units, of the area from which evaporation takes place. It is seen that **W** rises steadily as

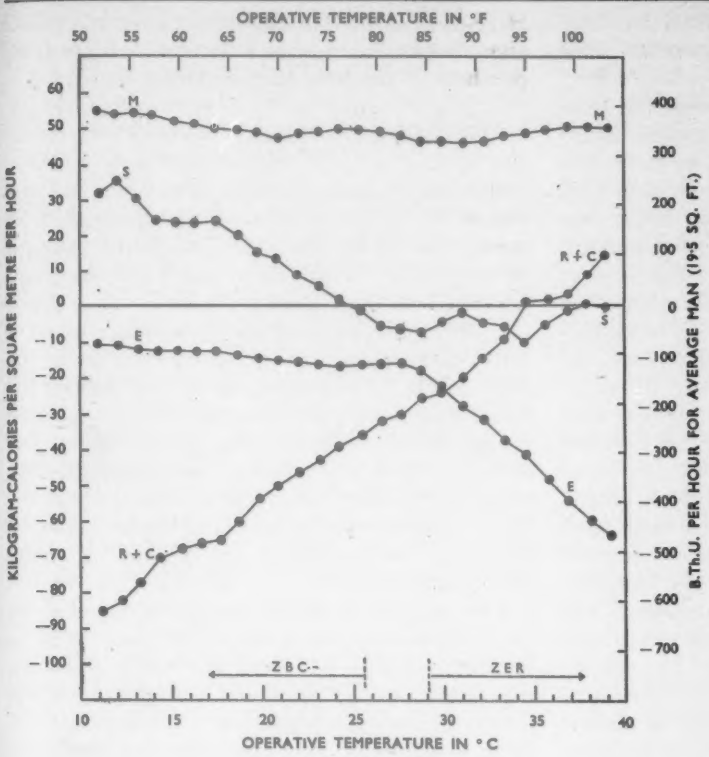
OPERATIVE TEMPERATURE IN °F
50 55 60 65 70 75 80 85 90 95 100
KILOGRAM-CALORIES PER SQUARE METRE PER HOUR
B.Th.U. PER HOUR FOR AVERAGE MAN (19·5 SQ. FT.)
M
S
E
R + C
ZBC
ZER
10 15 20 25 30 35 40
OPERATIVE TEMPERATURE IN °C

FIGURE 1 – *The relation of the different items in the heat exchange of the clothed body to operative temperature, with air movement of* 0·085 *metre per second* (17 *ft. per minute*) *and medium relative humidity.* M = *metabolic rate;* S = *storage rate;* E = *loss by evaporation;* R + C = *joint loss by radiation and convection;* ZBC = *zone of body cooling;* ZER = *zone of evaporative regulation.* (*After Winslow*, 1941, Temperature, its Measurement and Control in Science and Industry, 509.)

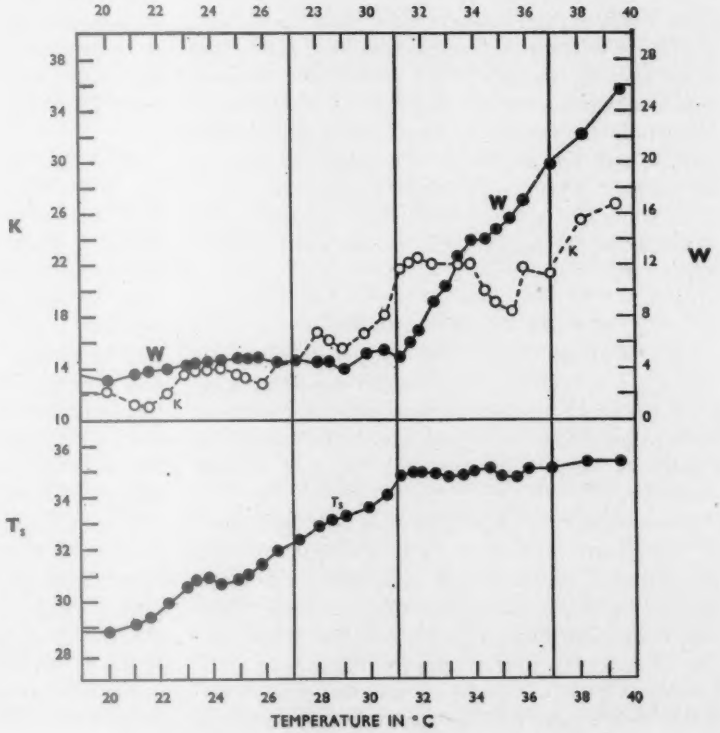

FIGURE 2 – *Physiological response to varying operative temperatures.* W = *wetted area of skin;* K = *conductance;* T_s = *mean temperature of skin* (*for nude subjects*). (*After Winslow*, 1941.)

the operative temperature rises above 31° C. Experiments indicate that there is a maximum value above which **W** does not increase.

The conductance, K, is a measure of the heat-conducting power of the body. It is equal to the sum of the metabolic and storage rates divided by the difference between internal and skin temperatures. Its value is nearly constant in the zone of body cooling, rises in the zone of vasomotor control, is substantially constant in the zone of evaporative control, and increases slightly in operative temperatures above 37° C. Conductance measures the readiness with which the body-heat is conducted outward to the skin. Experiments show that it is less in fat men than in lean men; and, so far as experimental data are available, less in women than in men. The latter fact is explained by women generally having a more considerable layer of subcutaneous fat than men; in addition, they show a readier tendency to increase their metabolic rate at low temperatures than men. For these reasons, women can bear with equanimity a degree of cold which men would find trying were they protected by only the same amount of clothing. But at higher temperatures the lower conductance of the body in women yields a slower flow of heat outward to the skin, while men sweat at lower temperatures, and sweat more freely at high temperatures, than do women. For these reasons men often find heat less trying than women, though these effects are to some extent counteracted by the greater tendency in women to decrease the metabolic generation of heat at high temperatures. The coloured races in the tropics, who are normally leaner than white men, show less visible sweat, their bodies having in consequence higher conductance than those of white men.

OUT-OF-DOOR CONDITIONS

Out of doors, when the sun is shining, the clothing and skin will absorb short-wave radiation from the sun and the sky, and in sunny weather in hot climates the clothing should be such as to reflect as large a fraction as possible of this radiation.

When the sky is clear there is a net loss of heat by long-wave radiation from the body to the environment, owing to the limited range of wavelengths in which the atmosphere radiates. This loss is sufficient to be important in the determination of comfort. It is a matter of common experience that on a hot night in summer it is appreciably cooler out of doors than indoors, partly on account of this additional loss of heat and partly on account of the longer retention by inner walls of rooms of the heat gained during the day.

THE EFFECT OF THE VARIATION OF AIR HUMIDITY

The rate of evaporation from the skin is determined by (*a*) the proportion of skin wetted by sweat, and (*b*) the difference between the vapour pressure of air saturated at the mean skin temperature and the vapour pressure in the ambient air. When the temperature of the ambient air is kept constant, and its humidity is increased, the body reacts by increasing the wetted area of the skin, whereby the total loss of heat by evaporation is maintained sensibly unchanged. The purpose of sweating is to maintain the thermal equilibrium of the body, and in any given circumstances the amount of sweating is limited to the lowest value necessary to maintain equilibrium of body temperature.

The skin temperature is scarcely affected by the relative humidity of the air, and only in air of relative humidity above 80 per cent., and temperature above 35° C, is the temperature of the skin appreciably higher than in dry air at the same temperature. At moderate and low temperatures, the loss of heat due to the production of insensible perspiration is independent of atmospheric conditions, and even of whether clothes are worn, being entirely conditioned by internal body factors.

THE EFFECT OF VARYING WIND-SPEED ON EVAPORATIVE LOSS OF HEAT

If we accept the postulate that evaporation of sweat is limited to the lowest value required to maintain body temperature constant, it follows that, in air of any assigned temperature and humidity, the effect of an increase in air-speed will be to increase the loss of heat by convection, and therefore to diminish the loss which must be provided by evaporation. Experimental data bear out this conclusion, showing that the evaporative loss decreases as the air-speed increases and the wetted area of the skin decreases.

The physiological reaction of the body to increasing relative humidity and decreasing air-speed, both of which factors would decrease the rate of evaporation from unit wetted area of the skin, is to increase the wetted area. This is a reaction which cannot be simulated by any instrument, and it is therefore not possible to devise an instrument which will produce a

response exactly parallel to that of the human body.

THE EFFECTS OF CLOTHING

The interposition of clothing between the skin and the environment checks the interchange of heat by radiation and convection between the body and the air, and provides a protection against either a cold or a hot environment. The loss of heat from the body by radiation and convection is less for the clothed than for the nude subject, but there is little systematic difference between the evaporative loss in the two cases for air temperatures below 35° C. Above this limit the evaporative loss is rather greater for the nude than for the clothed subject. The addition of more clothing will decrease the conduction of heat from the body to the air, just as the addition of another resistance in an electric circuit decreases the current, and the temperature of the trunk of the body can be maintained at a high level by the wearing of sufficient clothing.

THE EFFECTS OF PHYSICAL EFFORT

During physical effort, active sweating sets in at lower temperatures than for the reclining subject. When active sweating occurs, there is a marked fall of skin temperature over the whole body, which facilitates the increased flow of heat from the deeper parts of the body to the skin.

COMFORT IN INDOOR CONDITIONS

A large part of our lives is spent indoors, in conditions in which the evaporative loss of heat from the body is limited to that due to insensible perspiration and the evaporation in the lungs, so that the heat-balance is mainly controlled by radiation and convection. If it may be assumed that the radiating surfaces affecting the body have the same temperature as the air, the clothed body will lose heat by radiation and convection at a rate $(3{\cdot}6 + 10{\cdot}4\sqrt{v})$ units for every degree C difference between the temperatures of the air and of the surface which the body exposes to the air. Here v is the air speed in metres per second. The total rate of loss due to radiation and convection is thus determined by (*a*) the temperature of the ambient air, (*b*) the amount of clothing worn, and (*c*) the air movement. If the rate of loss of heat is too great for comfort, so that we feel cold, we may stir up the fire, put on more clothing, or close the window. When we feel too hot, we may let the fire burn low, shed some clothing, or open the window.

It cannot always be assumed that the effective radiating surfaces in the environment have the same temperature as the air. Inside a steel hut exposed to very bright sunshine the radiation from roof and walls may be so great as to make conditions intolerable. The ideal of painting the outside of such buildings with a highly reflecting enamel paint is not always practicable.

In very hot climates the radiation from the walls of buildings is a very important factor in the maintenance of body equilibrium, and so should be minimized as far as possible by constructing buildings of non-conducting materials of low heat capacity, with double walls and double roofs, separated by a wide air space. A thatched roof has these qualities, and is cool in summer and warm in winter.

In cold weather the walls of a house which has been left unheated during a long spell of cold weather retain their low temperature for some time after heating is started, with resulting discomfort even when the air temperature is reasonably high.

THE LIMITS OF EVAPORATIVE REGULATION; HEAT-STROKE CONDITIONS

When the metabolic rate is known and the skin temperature can be estimated, it is possible to write down an equation expressing the balance between the metabolic rate and the loss or gain of heat by radiation, conduction, and evaporation, in air of any assigned temperature, humidity, and air movement, provided that we may assume the radiating surfaces to be at the air temperature. The equation can be arranged to yield, for any assumed temperature, the maximum relative humidity in which heat balance can be maintained. This process has been followed, assuming air movement 17 ft. per minute, and the results obtained for a reclining subject are shown graphically in figure 3. Here curve AA gives the limits of tolerable conditions for the nude body, and curve BB gives corresponding limits for the clothed body when clothed as described in an early paragraph above. In conditions represented by a point to the right of the appropriate curve, the body temperature will rise, and will continue to rise so long as exposure to these conditions continues. The result will be to lead to heat-stroke. It is seen from figure 3 that, with very high air temperatures, the wearing of clothing is a marked protection against heat. The long loose garments worn by the Arab races afford such a protection against the heat of the air, while also reflecting a large fraction of the incident rays of the sun. In

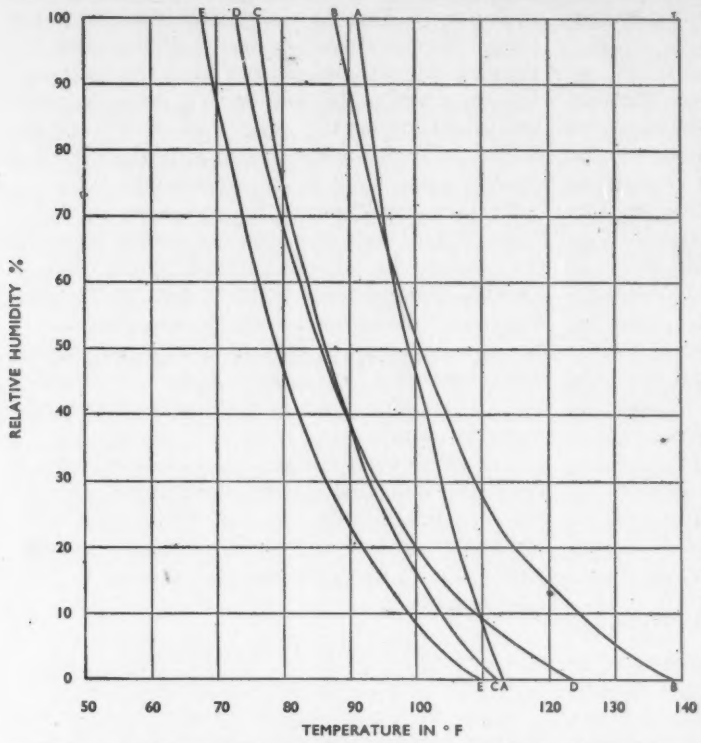

FIGURE 3 – *Curves showing the limits of the range of tolerable conditions for varying degrees of activity;* AA *for nude subjects resting indoors;* BB *for clothed subjects resting indoors;* CC *for clothed subjects resting in sunshine;* DD *for clothed subjects walking at 4 m.p.h. (no sunshine);* EE *for clothed subjects walking at 4 m.p.h. in bright sunshine.*

completely dry air the highest tolerable temperature for the clothed body is 138° F (curiously enough, the highest surface air temperature ever measured was 137·6° F, observed at Azizia, in Tripolitania), while for the nude body the highest tolerable temperature is about 113° F. In saturated air the highest temperature which is tolerable is 88° F for the clothed body and about 92° F for the nude body. This is in close agreewith the findings of J. B. S. Haldane and others, who give 88° F as the limiting temperature tolerable in coal-mines, even by men stripped to the waist and doing no work.

Curves AA and BB of figure 3 are appropriate for men resting, in conditions of light air movement. Any physical effort, by increasing the metabolic rate, will modify the limiting conditions and will shift the curve to the left in figure 3. The presence of sunshine will produce the same effect. Thus, even for a clothed man reclining in bright sunshine, there will be a zone to the left of Curve BB defining conditions in which continued exposure to bright sunshine will lead to heat-stroke.

Curve CC in figure 3 defines the limiting conditions for a lightly clothed man, reclining in bright sunshine, while the limiting conditions for the same man walking at 4 m.p.h., in the shade and in bright sunshine respectively, are given by DD and EE.

The outstanding feature of all the curves in figure 3 is that the drier the air, the higher the temperature which is permanently tolerable.

The statements made above do not preclude the possibility of remaining for brief periods in air at temperatures beyond the limits of permanent tolerability prescribed by the curves AA and BB of figure 3. Blagden described, in the *Philosophical Transactions of the Royal Society of London* in 1775, a stay of eight minutes in a room in which the air temperature varied between 240° F and 260° F. During the first seven minutes of his stay in this room Blagden experienced no discomfort, but after a further minute the rapid increase of distress in breathing and of a feeling of anxiety caused him to leave the room.

THE EFFECT OF INCREASED VENTILATION ON THE HEAT-STROKE LIMITS

When the air movement is increased, both the evaporative and convective losses of heat are increased. In figure 4 are given curves of the limiting conditions for a nude person resting, with six different rates of air movement. An increase of ventilation increases the temperature which can be tolerated with a given degree of humidity, and increases the relative humidity which can be tolerated with a given air temperature. The curves show that three factors are involved in the determination of tolerability of any given conditions. Conditions which are intolerable can be made tolerable by a lowering of air temperature, by a lowering of humidity, or by increased ventilation.

The effect of relative humidity of the air on the limiting conditions is at all times appreciable, and industries which from their nature are damp, as for example laundries, should be sited in places where the air is normally dry.

The higher degrees of air movement will yield very rapid evaporation of sweat, and the limiting conditions shown in figure 4 are based on the assumption that the body is then wetted by sweat to the maximum extent. A few figures for the rate of evaporation of sweat in the conditions prescribed by the curves are shown in the diagram, where they are expressed in weight of water evaporated in 1 hour by a person of average size. The total loss per hour is considerable, and there is a danger that, in such extreme conditions, the sweat-glands may become exhausted. Should this occur, so that sweating ceases, the body will then be heated by radiation and convection, and its temperature will rise steadily, leading eventually to death by heat-stroke. The deaths due to the simoom, the 'poison wind' of South Arabia, are probably to be explained in this way. Even if the sweat-glands do not become exhausted, but secrete at a limiting rate, there will be a definite wind-speed at which the sweat will evaporate as fast as it is secreted. If the wind rises beyond this limit, the evaporative loss will remain unchanged, while the gain of heat by convection from the air will increase; the result will eventually be death by heat-stroke.

The curves of figure 4 refer to nude persons, subjected to varying conditions of air movement. It is not possible at the moment to draw similar curves for clothed persons. The curve BB of figure 3, which refers to a clothed subject in air movement of 0·085 m. per second (17 ft. per

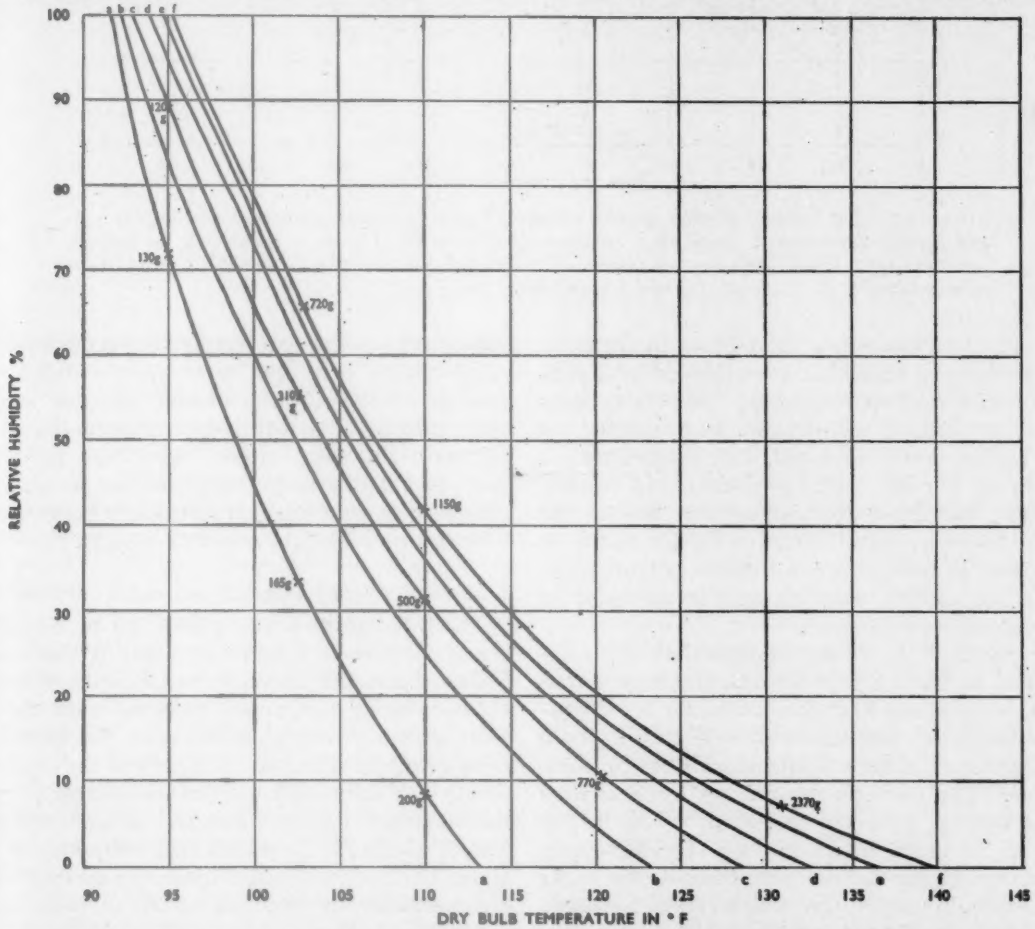

FIGURE 4 – *The effect of ventilation on heat-stroke conditions for nude subjects. The curves give limiting tolerable conditions,* aa *for air movement* 0·085 *metre per second* (17 *ft. per minute*); bb *for* 0·25 *metre per second* (50 *ft. per minute*); cc *for* 0·5 *metre per second* (100 *ft. per minute*); dd *for* 1 *metre per second* (200 *ft. per minute*); ee *for* 2 *metres per second* (400 *ft. per minute*); ff *for* 5 *metres per second* (1,000 *ft. per minute*). *Figures such as* 200g *marked on the curves indicate the rate of loss of water per hour by evaporation from the whole body, skin area being assumed to be* 1·8 *square metres.*

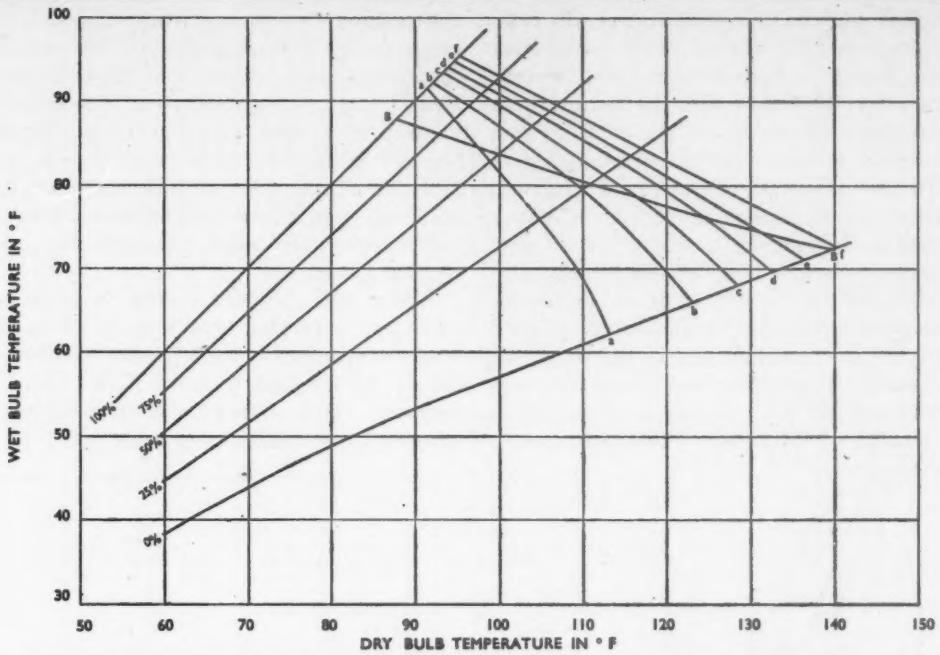

FIGURE 5 – *The limits of tolerable conditions shown in figure 4 converted for use with readings of wet- and dry-bulb thermometers. Curve* BB *is the conversion of curve* BB *of figure 3, representing the limiting conditions for a lightly clothed person resting. The diagonal lines indicate the conditions in which the relative humidity is* 0, 25, 50, 75, *and* 100 *per cent.*

minute), was based on a value of the conductivity of the clothing which had been derived by experiment with that air movement. But the conductivity of clothing will depend, in a manner not yet known, on the air-speed, since the penetration of the air into the clothing—particularly at neck, sleeves, and legs—depends on this factor. We may, however, take the curves for nude subjects as giving an indication of the effects of ventilation, even on clothed subjects, so far as order of magnitude is concerned.

In figure 5 are shown the same data as are described in figure 4, with air temperature and wet-bulb temperature as the variables, for use in conjunction with observations of wet- and dry-bulb temperatures obtained with a whirling psychrometer. The corresponding curve for a clothed man resting, with air movement of 17 ft. per minute, is added for comparison. It will be seen that, the higher the air temperature, the lower the wet-bulb temperature which can be tolerated.

If we require to determine whether any particular climate will be permanently tolerable, we must consider air temperature, humidity, and wind-speed. The worst conditions are those associated with very light winds, and it is often sufficient to consider air temperature and humidity only. But it is dangerous to assume that it is possible to lay down a definite limit of mean temperature above which man cannot live and prosper. Humidity rather below the half-way limit, or a high average wind-speed at the hottest time of day, may make a somewhat high mean temperature both tolerable and healthy.

COMFORT, HEALTH, AND EFFICIENCY

The limiting conditions prescribed by the diagrams of figures 3, 4, and 5 are those in which the body temperature could be maintained constant, the body being then wetted by sweat to the maximum extent. Such conditions are far removed from comfort. The nude subjects of the experiments by Winslow, Herrington, and Gagge found the maximum feeling of comfort in air temperature of about 29° C, with a skin temperature of about 33° C; for clothed subjects the corresponding temperatures were about 27° C (air) and about 33° C (skin).

We cannot apply these results to the estimation of the conditions of greatest comfort for men leading a normally active life. Comfort is indeed a factor which is difficult to define with clarity.

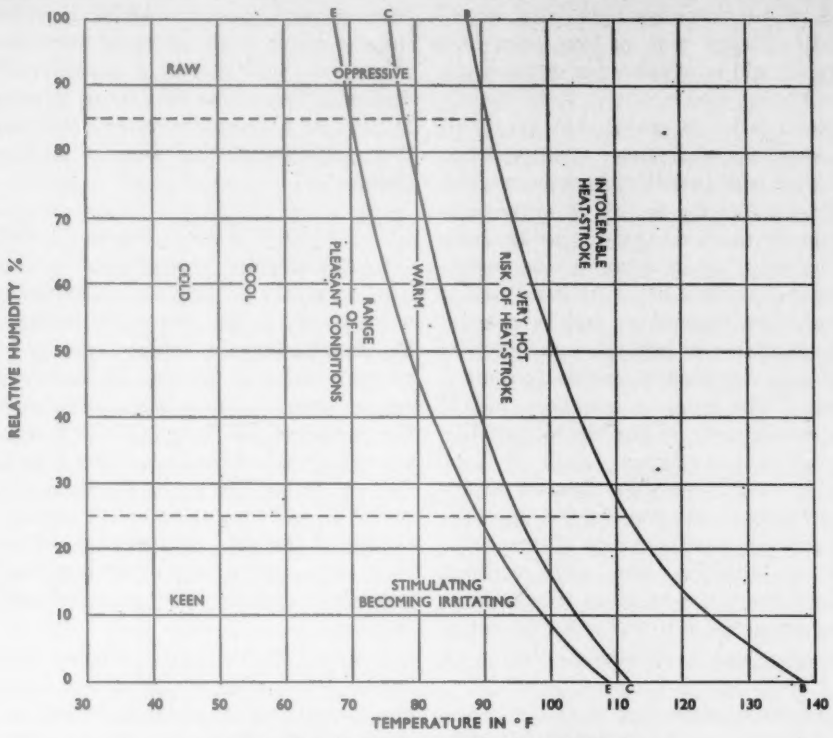

FIGURE 6 – *A tentative classification of climates.*

The slightest physical effort, and even standing up instead of reclining, will raise the metabolic rate, which modifies the heat balance of the body. There appears to be no simple method of carrying the argument further, and we are forced to appeal to purely qualitative observations of comfort or discomfort in different conditions. A tentative summary of such results as appear to be definite is given in figure 6, and this diagram may be taken as a tentative classification of climates. It is based on the assumption of light air movement, 17 ft. per minute, since we have to provide that conditions shall be tolerable when the wind falls off almost to a calm.

In figure 6, the line BB has been copied from figure 3. This line represents the limits of tolerable conditions for a clothed person resting, with air movement of 17 ft. per minute. To the right of this line are conditions of temperature and humidity such that continued exposure leads to rise of body temperature, followed by heat-stroke. The region to the right of line BB in figure 6 is therefore marked 'heat-stroke.' To the left of this line there is a region in which conditions will be classed as 'very hot,' even by a person resting, while a relatively slight physical effort will cause the body temperature and the pulse-rate to rise. The line CC of figure 3 has been inserted as the lower limit of the 'very hot' region, on the assumption that 'very hot' applies to conditions in which it is impossible to walk at 2 m.p.h., or to rest in bright sunshine, without rise of body temperature.

A region to the left of CC is marked 'warm,' and this region is bounded on the side of low temperatures by the line EE, which represents approximately the limiting conditions in which a man can walk at 4 m.p.h. in bright sunshine without rise of body temperature. This boundary is tentative, and is possibly too far into high temperatures for very low humidities.

The lowest temperatures which are tolerable or comfortable are not readily fixed. It is generally agreed that below 50° F it is 'cold,' and that below 60° F it is 'cool,' except for a man making a considerable physical effort. The cold region, below 50° F, may be further subdivided. Damp air, of relative humidity above 85 per cent., then yields the conditions known as 'raw,' the discomfort of which is due to condensation of water vapour in the clothing, leading to an increase in conductivity of the clothing, and consequently to increased convective loss of heat. At

the other end of the humidity scale, dry air, of relative humidity 25 per cent. or less, gives that stinging feeling of cold to which we give the name 'keen.'

Saturated or nearly saturated air is at all temperatures unpleasant. Even at a temperature of about 70° F, it is distinctly oppressive, and at very high temperatures the feeling of oppression becomes still more marked. Again, while short exposure to very dry air is found to be rather stimulating, long-continued exposure is irritating, leading to headaches, depression, lack of energy, and a strong tendency to become quarrelsome. This action of very dry air is particularly noticeable where the Föhn wind is common, but is observable in many parts of the world, notably among dwellers in desert regions.

Within the limits of desirable climates tentatively fixed by figure 6 between the 60° line and EE, there yet remains a wide choice of temperature and relative humidity, and with medium relative humidity there is a range of temperature extending from about 60° F to 75° or 80° F within which a man may feel a reasonable degree of comfort.

Experience of air conditioning in many countries has shown that it may be accepted that with relative humidities of 40 to 70 per cent. men doing light work indoors can do so with maximum comfort in air temperatures above 60° F and below 76° F. The optimum actually prescribed will vary in different countries, according to the clothing worn, the degree of physical activity, the average conditions out of doors, and the type of heating and ventilation used. It is agreed that very high and very low degrees of relative humidity are to be avoided—high values because they lead to a feeling of oppression and low values because they eventually produce restlessness and irritability. The differences in what are regarded as the optimum conditions in different countries may be illustrated by a comparison of the recommendations for indoor air conditioning made in England and in the United States. With medium relative humidity the summer optimum is 66° F in England and 76° F in the United States; and the winter optimum is 62° to 64° F in England and 72° F in the United States.

In such climates as those of most countries in the middle latitudes of both hemispheres, some degree of air conditioning is necessary in order to produce indoor conditions compatible with comfort and efficiency. In England and other parts of the British Isles the heating of homes is still very largely by open coal fires, and should the same method continue to be used in the future, cheap coal will remain a necessity if the health and efficiency of the nation are to be maintained. If the coal fire should be replaced by some other form of heating, that form of heating must be cheap.

SEEKING THE IDEAL CLIMATE

In any attempt to determine the ideal climate it is necessary to bear in mind the variation of temperature at any one place during the twenty-four hours of the day. This variation may amount to over 40° F in certain localities. The lowest temperatures occur at about sunrise, and most of the period of low temperatures comes at a time when the bulk of the population is in bed. Under the bedclothes the air temperature is usually 85° to 86° F. We may therefore discount some of the effects of the diurnal variation of temperature, since exposure to low night temperatures is restricted to a relatively short period for the average citizen.

If we accept the limits of figure 6 as fixing the limits of desirable climate to a reasonable degree of certainty, we may conclude that, with average relative humidities, the temperature to which a man is exposed when he is not making great physical effort should lie between 60° F and about 75° F. We may therefore define the ideal climate as one in which the air temperature rarely exceeds 75° F, and rarely falls so low that it becomes difficult to raise the indoor temperature to that value between 60° and 75° F which is regarded as desirable. When air temperature falls below the freezing-point even by day, it becomes costly and troublesome to maintain an indoor temperature of over 60° F.

It is estimated that in bright sunshine and with air temperature 67° F a lightly clothed man could walk at a rate of nearly 4 m.p.h. without sweating, and could either sit in the sun or stand in the shade doing light work without body cooling. This would appear to fix an ideal for an active outdoor life for a lightly clothed man. With little or no clothing, a somewhat higher temperature would be desirable, so that the ideal would probably exceed 70° F.

At this stage it is of some interest to look at a world map of the mean temperatures of the year. On such a map, the isotherm of annual mean temperature 70° F passes through Memphis, Palestine, and the centres of the early civilizations of Assyria, Sumeria, Persia, and not far north of

the site of the early Indian civilization at Mohenjodaro in the valley of the Indus. The early civilizations of Africa and Asia thus arose in regions where the mean temperature of the year was very close to 70° F. The summer would have been hotter than this, and summer afternoons probably so hot that the siesta must have been a biological necessity rather than a luxury. The winter would have been too cold for comfort without some special protection. In none of these ancient civilizations was the heating of buildings customary, and it was only when the control of indoor temperatures became common, in the days of Greece, and still more in the Roman Empire, that an advanced civilization developed at an appreciably lower annual mean temperature than 70° F. After the fall of the Roman Empire, the custom of controlling indoor conditions slowly died away, and the next civilization, the Muslim, was in the region of the 70° isotherm. It was only with the rediscovery of brick-making, the invention of the fireplace and chimney as we know them, and the use of glass for windows, all in the thirteenth century, that any degree of winter comfort became possible in most European countries. By the middle of the sixteenth century, the middle and upper classes in England had draughtproof houses, with glass windows instead of slits in the walls, and with coal-burning fireplaces and chimneys. The general use of coal spread to the villages soon after this period. It may not be without significance that the glories of the Tudor era in England came so soon after the use of coal for heating had become common. England's very plentiful supplies of coal gave her a great advantage over many of her competitors in the race for superiority which she eventually won.

According to F. S. Markham's book, *Climate and the Energy of Nations*, when a white man migrates to a country where the hottest month of the year has a mean temperature exceeding 75° F, he finds that, whereas he and his children may be able to cope with the altered climatic conditions, his grandchildren will show a marked loss of energy and of efficiency, both physical and mental. It is doubtful whether this rule holds in all its simplicity for all countries. Some allowance must be made for atmospheric humidity, as well as for the effect of wind-speed, on the tolerability of otherwise hot conditions. Major Markham has, however, marshalled a considerable mass of material, relating to health and economic conditions, which appear to bear out his views as to the general range of climatic conditions which are permanently tolerable by white men, and to suggest that the 'poor white' problem is partly climatic. There is, however, a wide range of problems of settlement of white races still remaining to be investigated, and as the problems of the settlement of white peoples in hot climates promises to become important at the close of the present war, it would appear highly desirable that there should be a world inquiry into these problems, which are not entirely limited to economic and medical factors, but include also an important climatic factor that cannot be neglected.

The ideal climate would seem to be one in which the mean temperature of the hottest month of the year does not exceed 70° F, or at most 75° F, while the mean temperature of the coldest month does not fall below 40° F, or at lowest below 32° F. New Zealand offers what is in many ways the most attractive approach to this ideal, as over most of the country the mean temperature of the hottest month lies between 62° and 70° F, while that of the coldest month lies between 45° and 52° F. The healthy nature of the climate is borne out by the fact that, during the ten years 1926–35, New Zealand had a death-rate and an infantile mortality-rate of 8·4 and 40 respectively, both the lowest recorded values for any country in the world. The corresponding rates for the United Kingdom were 12·2 and 67 respectively.

Types of man-made fibres

W. T. ASTBURY

'You will never make a Sattin purse of a Sowes ear,' said the old proverb. This precise metamorphosis is still impossible, but chemists have closely approached it: for from the fats and proteins of a sow's ear it is possible to synthesize nylon, one of the most successful of man-made fibres. Dr Astbury, who with his colleagues has made the chief advances in the protein fibre field, has a fascinating story to tell of man's rivalry with Nature.

Biological fibres are of the nature of molecular yarns spun from long chain-molecules. It may seem almost obvious to us now that this should be so, but in fact it is a generalization that has emerged clearly only within the last twenty years. And it is one of the great generalizations of our time, not simply as regards its industrial implications, gratifying though they are, but in a much wider and more wonderful sense. In the make-up of living tissues chain-molecules are pre-eminent, and the study of their forms and combinations is fast laying the foundations of a new biology. It is not directly with such high adventures, however, that we are concerned here, but rather with some of the lessons that have been learnt from them. The purpose of this article is to explain how man has set about making fibres in Nature's image, and to classify the results of his efforts in terms of chemical constitution and physical properties.

In what follows we shall be wise after the event and talk as though there was always a conscious striving after suitable kinds of chain-molecules and methods of spinning them. That, of course, is not so. There must long have been the desire to imitate spiders and silkworms by some process of extruding and coagulating viscous solutions—witness, for example, Hooke's whimsical suggestion, in his *Micrographia* (1664), of 'a pretty Kinde of artificial Stuffe' that might be drawn into fibres—but until comparatively recently that seems to have been as far as it went. Success came empirically in the latter half of the nineteenth century with the discovery how to dissolve and resolidify cellulose and some of its derivatives; and though it was recognized that the molecules of cellulose must be very large and that the high viscosity and 'spinnability' of its solutions were bound up with this fact, it remains that people were wearing 'artificial silk' before their benefactors properly understood what they were doing. The story would sustain a nice argument between those who contend that scientific progress reflects the demands of the age and those who hold rather that scientific advances actually inaugurate new eras. It is impossible to dissociate fibre science from a strong industrial urge, but likewise it is undeniable that researches into more and more complex molecules, particularly those of biological origin, were in any case reaching an exciting stage. The important point is that the two lines of approach have now run together into what in the end amounts to a single subject, the study of chain-molecules—and whether they are in hair or nylon, eggs or plastics, cabbages or kings, matters little.

In the biological world, as just said, fibrous structures, or what are effectively fibrous structures when we penetrate to the molecules themselves, are of the very nature of things; and similar types of chains are used over and over again in all sorts of guises and groupings. Since, then, such chains, in the long trial of evolution, have been found worthy of so heavy a responsibility, the obvious first course in attempts to make fibres of our own would be to make further use of the self-same molecules, either by collecting them from natural sources or by synthesizing them. On the long view the latter procedure is the more satisfactory, but for the present our chemistry is not equal to the task, and we can do no more than refashion or remould existing raw material. This is the basis of the 'regenerated' fibre industry—the science of isolating, controlling, and if necessary modifying, natural chain-molecules and building them into structures of our own design. In the meantime, however, pending the day when we shall have succeeded in synthesizing some of the more difficult components of ourselves and other living creatures, there is no reason why we should not try to evolve other chain-molecules—simpler ones, of course—and make play with those, thereby at the same time generating new effects, over and above those already met with in

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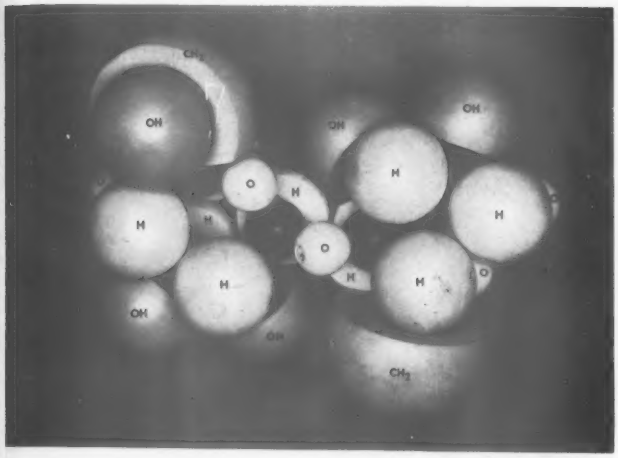


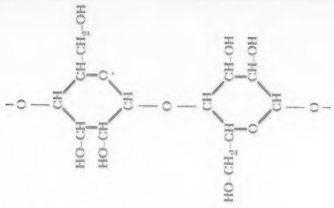


FIGURE 1 – *Scale model of two consecutive links in the cellulose chain.*

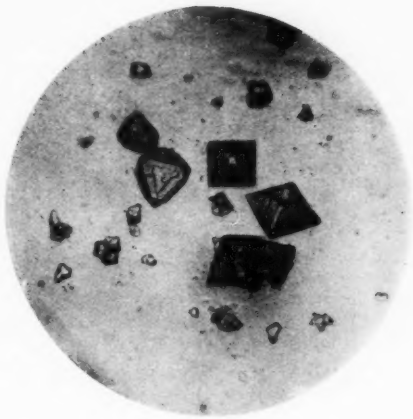
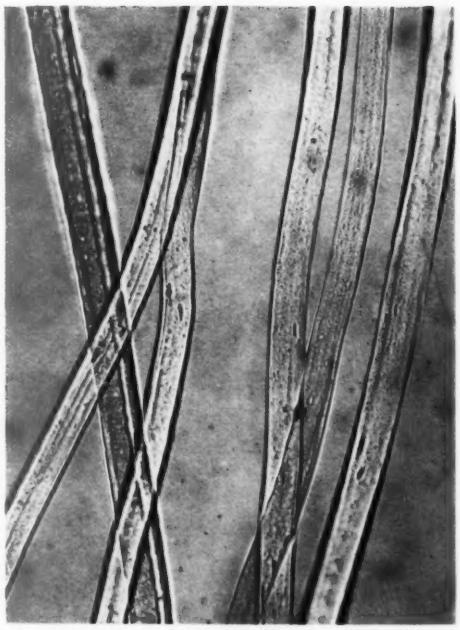


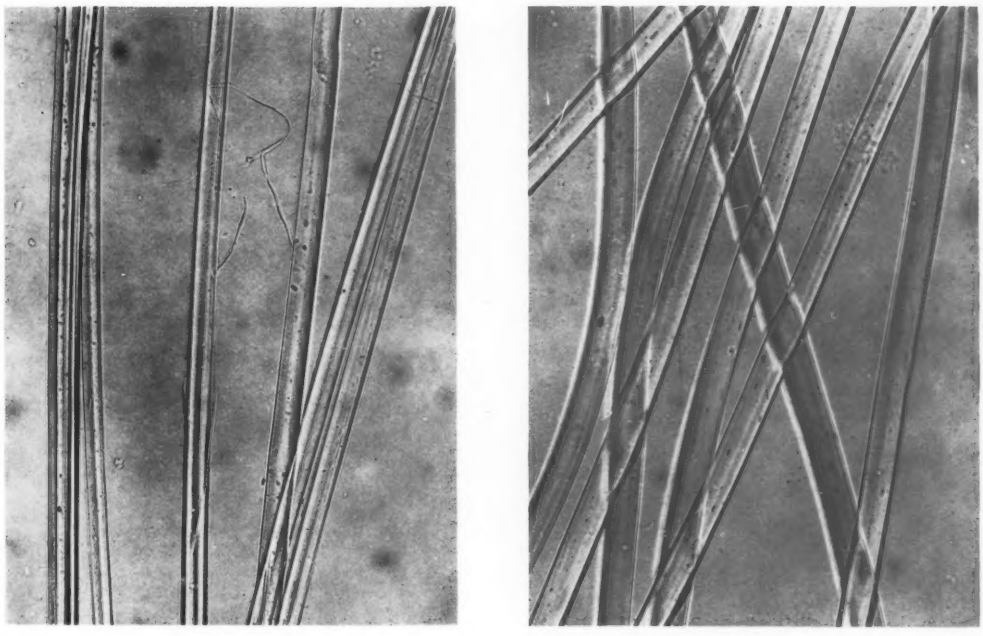
FIGURE 2 – *Microscopic crystals of edestin, the globulin from hemp-seed.*

(*a*)



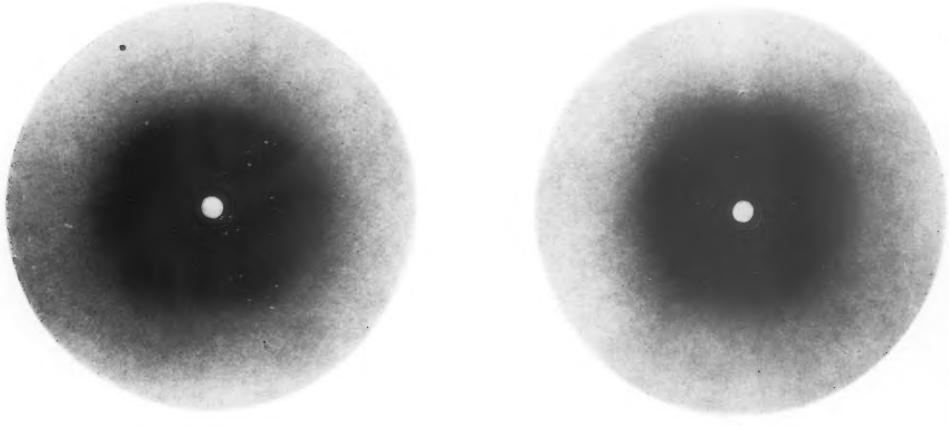
(*b*)

FIGURE 3 – *Regenerated protein fibres:* (*a*) *from the arachin of pea-nuts;* (*b*) *from the casein of milk.* (× 250.)
(*Photomicrographs by J. Manby, University of Leeds.*)



(*a*) (*b*)

FIGURE 4 – *Synthetic fibres:* (*a*) *'vinyon';* (*b*) *nylon.* (× 250.)
(Photomicrographs by J. Manby, University of Leeds.)

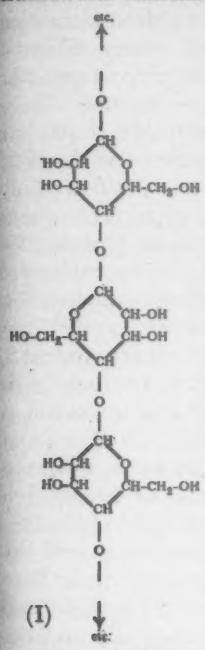


(*a*) (*b*)

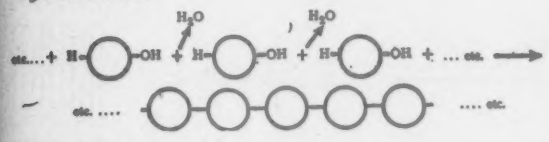
FIGURE 5 – *X-ray photographs of 'vinyon':* (*a*) *stretched;* (*b*) *contracted in steam to about one-fifth of its stretched length. (Fibre axis vertical; CuKa-rays;* $D \approx 3$ *cm.)*

Nature. This is the basis of the synthetic fibre industry—the science of making fibres 'from scratch'[1].

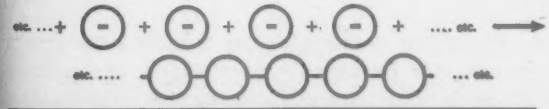
The two classes of regenerated fibres start one from polysaccharides and the other from proteins. The polysaccharide-in-chief is cellulose, the main framework substance of the vegetable kingdom and the most abundant organic compound in nature. The cellulose molecule (I) is a chain of hundreds or thousands of β-glucose 'residues.' It is worth while delaying for a moment to make clear the meaning of the word 'residue,' since it is sometimes loosely stated that the cellulose molecule consists of a chain of β-glucoses, or that the proteins consist of chains of α-amino acids. The two methods of building chain-molecules are by repeated condensation or by polymerization, the former process involving at each linkage the elimination of (generally) the elements of water, and the latter the opening of a double bond followed by direct addition. With sufficient generality for our purpose the two schemes may be represented symbolically as follows:



Polycondensation



Polymerization



[1]It is perhaps unfortunate that there is as yet no agreed nomenclature for man-made fibres. The need for such agreement is likely to become more pressing as chemistry makes increasing advances into the realm of textiles. The words 'rayons,' 'prolons,' and 'synthons' have been proposed for fibres of cellulosic, protein, and synthetic origin respectively; but these are not generally acceptable. A proposal to use the word 'rayon' to cover all non-natural fibres is even less acceptable, while the word 'artificial' is felt in the textile trade to be derogatory. For the purposes of this article we accordingly fall back on the broad classification into 'regenerated' and 'synthetic.'

The linked units in either case are called residues, and the chain is usually spoken of as a high polymer, whether it was formed by polymerization or not. Cellulose $(C_6H_{10}O_5)_n$ is formed from β-glucose, $C_6H_{12}O_6$, by the process of condensation. Formula (I) is a convenient quick way of writing down the atomic arrangement, but it is no more than that, because chains of residues of other sugars may be written similarly. It requires perspective drawings or models to show the spatial relations of the hydroxyl groups and the configuration of the molecule as a whole—and, it should be emphasized, such things are indispensable in the scientific study of fibre structure. Figure 1 will convey some idea of the actual shape of the unit that runs through the cellulose story. The chains themselves are very long and somewhat stiff, and in the more crystalline regions of the fibres they are stereochemically fully extended and are held together strongly by means of hydrogen bridges between hydroxyl groups[1].

There is no question of melting cellulose and redrawing it from the molten state as may be done with many synthetic high polymers: natural structures, such as wood, have to be broken down, purified from non-cellulosic constituents, and dissolved in special solvents such as our old laboratory friend, Schweitzer's reagent (cuprammonium). In the manufacture of viscose, the commonest type of rayon, the cellulose is brought into solution by a combination of caustic soda and carbon disulphide and regenerated by squirting through the fine holes of a 'spinneret' into an acid bath. The regenerated cellulose molecule appears to be essentially the same as in the native state, except that it is likely to be shortened by hydrolysis at some of the bridges between the glucose residues. X-rays show, however, that the state of side-to-side aggregation is different: the product is what is known as hydrate, or mercerized, cellulose, being crystallographically the same as that into which native cellulose is transformed in the well-known process of mercerization, which does not involve solution proper, but a mere swelling with alkali and water.

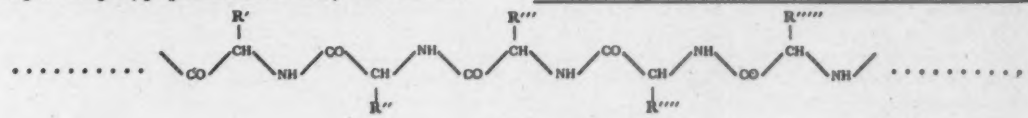
The properties of artificial filaments depend on the chemical constitution of the chain-molecules, and on the length, orientation, and regularity of the chain-bundles or 'micelles.' Strength, for

[1]We may perhaps dispense with reproducing any X-ray photographs of cellulose or its derivatives because they are now fairly familiar. The reader will find a selection of X-ray fibre photographs in an article by the writer in the April 1942 number of ENDEAVOUR.

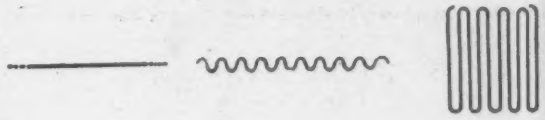
instance, is a function of the degree of crystallinity and parallelism to the fibre axis. X-ray analysis provides the best all-round help in keeping track of fibre properties in terms of internal arrangement, and the subject owes a great deal to it; but to feel happy in the field requires much more, a co-ordination of techniques and data that may be no more than hinted at in an article of this kind. The cellulose story alone is immense—filaments of cellulose and its derivatives are still overwhelmingly the commonest of man-made fibres—but briefly we may say that it falls into three parts. The first has to do with 'straight' regenerated cellulose (products such as viscose, cuprammonium rayon, and so on), while the second is concerned with chemically modified cellulose, derivatives such as ethers and esters, the most notable example of which is acetate rayon. Substitutions in the hydroxyl groups of the glucose residues can of course give rise to a great range of molecular affinity, both between the chain-molecules themselves, leading to a variety of mechanical properties, and between the chains and accessory reagents—dyes, for example. It should be added that the uses of regenerated cellulose and its derivatives are not confined to fibre production: there is a considerable industry devoted to the manufacture of films, sheets, and other shapes.

The third part of the cellulose story is by way of being an intercalation on processes for imparting properties that are more the prerogative of the protein fibres. 'Tebilizing,' for instance, makes cellulose fabrics crease-resisting through an intimate incorporation in the fibre substance of the cross-linked chains of urea-formaldehyde resin, while so-called 'animalized' rayons show certain protein dyeing properties by virtue of the presence of other synthetic polymers. This brings us now to the field of the regenerated protein fibres, in which the technological development finds much of its inspiration in a desire to imitate the natural protein fibre, wool, more closely still. The underlying scientific ideas derive mostly from the X-ray interpretation of protein structure, and particularly from the X-ray discovery of the general relationship between the fibrous and the crystalline, or 'corpuscular,' proteins.

The proteins are organized systems of polypeptide chains, alone or in combination with prosthetic groups. A polypeptide chain may be written:



where R′, R″, etc., stand for about two dozen different kinds of side chains that theoretically may be distributed in an enormous number of ways. That is to say, whereas cellulose is a polycondensation product of β-glucose only and (except for end-groups) consists therefore of residues of a single kind, the proteins are polycondensation products of α-amino acids of widely different chemical functions whose residues have only the formula (–CO–CHR–NH–) in common. As a result, the conventional polypeptide chain just set out hardly begins to portray the stereochemical possibilities. Even in the protein *fibres* the fully extended configuration already given is comparatively rare. It is found in natural silk (fibroin), for example, but in mammalian hairs the chains are normally in a regularly folded configuration (α-keratin), from which they are pulled out straight (β-keratin) when the fibres are stretched, and to which they return when the tension is removed. This intramolecular transformation is the basis of the long-range elasticity of a great family of fibrous proteins that includes, as shown by X-rays, not only the keratinous fibres such as wool and so on, but also those of the epidermis, the elastic protein of muscle (myosin), and the blood-clotting protein, fibrinogen. All these have a similar shape of molecule that lies intermediate between the fully stretched form of silk and the highly folded forms of corpuscular proteins such as egg-albumin, haemoglobin, edestin, etc. The transition from one extreme to the other may be represented diagrammatically as follows:

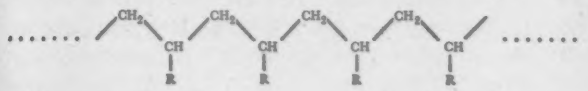


β α *Corpuscular*

When the intramolecular folds specific to a protein are irreversibly disarranged, the protein is said to be 'denatured,' and the science of making regenerated protein fibres consists in unfolding suitable corpuscular molecules by the action of denaturing agents and drawing out the liberated polypeptide chains into less folded, elongated configurations. Sufficient vestigial folds remain to endow the product with a long-range elasticity

roughly analogous to that of wool. The denaturing agent may be an alkali or strong urea solution, and the viscous solution so produced is then spun into coagulating and hardening baths. The milk protein, casein, was one of the first to be converted into fibres in this sort of way—along empirical lines, however—but following the X-ray elucidation of the process it is now known that many other corpuscular proteins offer themselves, particularly the seed globulins found in pea-nuts, soya beans, and the like. Figures 2 and 3 (*a*) and (*b*) will bring home the dramatic nature of the change from crystalline protein to soft, elastic fibres—incidentally, as striking a demonstration of the unity of the physical, chemical, and biological sciences on the one hand, and of science and industry on the other, as may well be imagined.

The regenerated protein fibre industry is still in its infancy, and so is the synthetic, to which we now turn to complete this skeleton-like sketch of a tremendous body of knowledge and craftsmanship. Synthetic fibres are resins or plastics often spun from the molten state, and their production is an affair of modern chemistry and chemical engineering[1]. The two general methods of building up linear high polymers have been indicated above, and all we shall add to that is to say that both schemes are in use, and already with such success that, under appropriate physico-chemical conditions and with the aid of catalysts, it is now possible to synthesize chains many thousands of residues long. Favourite monomers are vinyl and vinylidene derivatives, polymerizing to chains of the type:



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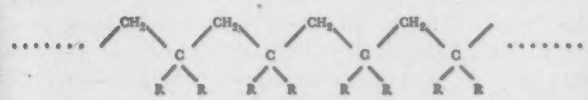
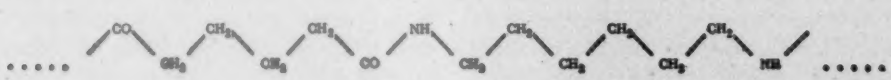


Not all such chains are fibre-forming in the best technological sense, however, because their physical properties in the mass depend on their length, the nature of the R-groups, and the temperature. Broadly speaking, good fibres are formed by long chains with not too much sideways asymmetry, though that is not the whole story by any means. Temperature is a very important factor—linear high polymers belong to the class known as 'thermoplastics,' and a product that is hard and brittle at low temperatures generally becomes plastic or rubbery at higher temperatures. What seems to have been the first commercial synthetic fibre is 'vinyon' (figure 4 (*a*)), a co-polymer of vinyl chloride, $CH_2=CHCl$, and vinyl acetate, $CH_3{\cdot}COOCH=CH_2$. An X-ray photograph of a specimen of 'vinyon' that had been submitted to an extra stretching in the laboratory is shown in figure 5 (*a*), while figure 5 (*b*) is a photograph of the same specimen after exposure to steam. It is included to illustrate the property of thermo-elasticity, so characteristic of many linear high polymers. Above about 70° C (in the case of 'vinyon') thermal vibrations disarrange the chain-molecules that at ordinary temperatures remain 'frozen' roughly parallel to the fibre axis (*see* figure 5 (*a*)): they coil up and the fibre rapidly contracts to only a fraction of its initial length. Figure 5 (*b*) shows the almost amorphous nature of the contracted state.

The most successful synthetic fibre to date is nylon. This is a class-name that has been given to polyamides formed by the repeated condensation of dicarboxylic acids and diamines, generally of the type $COOH{-}(CH_2)_x{-}COOH$ and $NH_2{-}(CH_2)_y{-}NH_2$. The acid and base commonly employed are adipic acid and hexamethylene diamine respectively, leading to chains of the formula below. Nylon has an exceptionally low affinity for water, and it can be drawn into thicker filaments for toothbrushes and surgical sutures, for example, or into the finest fibres with the strength and resilience of natural silk. So outstanding are its properties that nylon is monopolized for the time being almost entirely for war purposes.



[1]See, for example, the article on polythene by J. C. Swallow in the January 1944 number of ENDEAVOUR.

Movements of the tongue in speech

J. YULE BOGUE and DENNIS FRY

To understand the mechanism of speech, a close study of the movements of the tongue is essential. This presents obvious difficulties under normal conditions, but recently a unique opportunity arose of cine-photographing tongue movements during speech. A simultaneous sound-record was made, and some of the most important conclusions are described in this article, which is illustrated with remarkable photographs taken from the film.

Though many languages are spoken and many different pronunciations, even in one language, are recognized, the mechanism by which speech is produced is the same in all cases. The organs involved are the lungs, which serve as an air reservoir, the larynx, the soft palate, the tongue, and the lips, all of which modify the outward passage of the air-stream in such a manner as to produce speech. It is, however, the tongue which is largely responsible for those sound differences which characterize a particular pronunciation. For this reason a study of the tongue in movement is essential for a proper understanding of the mechanism of speech.

Until recently, our knowledge of these movements has been gained very largely by subjective investigation—that is, by a subjective correlation of muscle movements with the auditory impressions of the sounds produced by them. One consequence of this has been a tendency to connect the different speech-sounds with a series of static positions of the tongue rather than to consider the effect of its movement.

The co-operation of a patient whose tongue was exposed to view as the result of an operation involving the removal of his right cheek enabled us to record on film both the sounds and the tongue movements.

The words and sentences recorded were chosen so that the film might cover the widest possible range of sounds. We have, in fact, records of all English sounds except a few which occur but rarely, and certain labial ones which were deliberately omitted because the subject's lip movements were abnormal. The film presents the material in three sections: first, a group of isolated words demonstrating the movements which accompany the production of various vowels; second, a series of words all containing the same vowel preceded and followed by different consonants; and third, some short sentences showing the action of the tongue in current speech.

The subject, 72 years of age, was born in London and has lived there all his life. Certain of the sounds he uses are characteristic of the London regional accent. His speech habits have not yet been very much affected by adaptation to his new condition.

In the work which we are describing here, all possible means were adopted to increase the value of the records obtained. The chief source of information is a 'Technicolor' film record of the tongue movements taken at the normal rate of 24 frames per second. A simultaneous sound recording of the subject's speech was made, so that it is possible to compare the pictures with the sounds corresponding to the tongue movements. Further, the film sound-track, which is of the variable area type, supplies a rough indication of the wave-form of the sound which is being produced. In addition to these records made at normal speed, high-speed photographs were taken at a rate of 1,000 frames per second. These shots can be projected at the normal rate, so that the tongue movements are slowed down approximately 40 times; they are, however, intended mainly for frame-by-frame analysis in conjunction with cathode ray oscillograms of the speech-sounds taken at the same time. This analysis in itself will constitute a long research project, and it is impossible, at present, to state what new light may be thrown upon the subject. The results will be particularly valuable because the high speed at which the record was obtained ensures that every movement of the tongue may be followed to its limits.

The normal-speed film has already revealed facts of general interest; it is possible to give here only one or two examples. The traditional method of classifying vowels by tongue 'position' refers different vowel qualities to the part of the tongue concerned in their articulation. The film record shows very strikingly that the general shape which the tongue adopts, and the movement of the whole

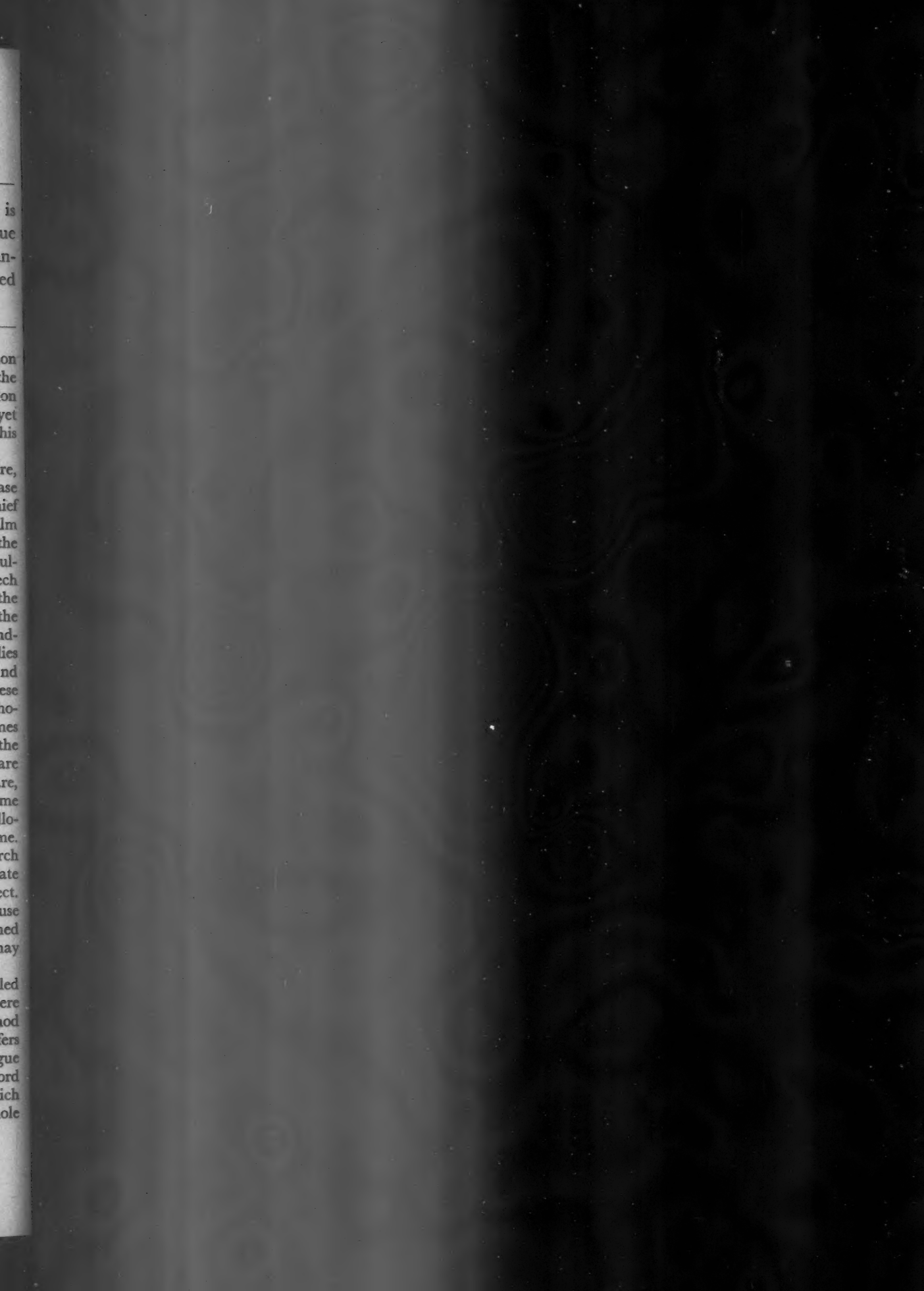
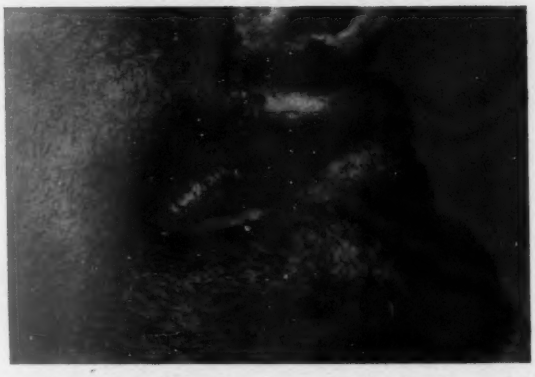


FIGURE 1 – *The forward contact for* l *in* lad.

FIGURE 2 – *The tongue-tip rolls back for* r *in* rag.



FIGURES 3 and 4 – *In both* s *and* sh *the tongue shows a characteristic furrowing, but moves further forward in* s *than for* sh.

tongue with relation to the mouth cavity, are the governing factors in determining vowel quality. So, for example, in the vowel series of *he*, *him*, *hem*, *ham*, where the traditional theory would expect a progressive lowering of the front of the tongue, the film shows that the modification of vowel quality is achieved by bunching the tongue together rather than by any considerable lowering.

Perhaps the most striking of the demonstrations supplied by the film concerns the welding of a succession of sounds into a continuous chain. As soon as we see the tongue really in movement it is evident that all movements during one sound-group must be interdependent. The idea of a series of 'tongue positions' giving rise to a series of sounds appears quite artificial, and the theory of assimilation (that is, the influence of one sound upon another) loses much of its meaning. The film shows that often a very small movement of part of the tongue is sufficient to produce in one context the acoustic impression of a particular sound which in another context may require a full-scale movement of the whole tongue. A good example of this is provided in the film record of the sentence *There's a crowd in the back room*, where the vowel of *in* entails only the slightest movement of the tongue-tip, whereas the 'same vowel' in *him* shows a considerable movement of the whole tongue.

The business of learning to speak, which most of us perform quite naturally by imitation, does in some cases require external aids. The deaf-mute, for example, has to be taught to speak through a long and laborious process of learning to make the correct muscle movements deliberately, and in some cases of nervous disease it may be necessary to carry out complete speech re-education. Even less complicated tasks, such as learning to pronounce a foreign language, entail the learning of new muscular habits. The primary aid to this process is the ear, and where the hearing is normal we may be sure that it will do

FIGURE 5 – *The tongue in a typical rest position.*

the major part of the work. Even so, it is often necessary to assist the ear with various visual aids. When the hearing is defective, acquisition of the muscular habits of speech depends on the visual and kinaesthetic senses, and we have to seek ways of presenting the speech processes to the eye.

The sound film of tongue movements has suggested a new technique for this purpose. We have now at our disposal a moving picture of the tongue as it produces the sounds used in pronouncing English. Any part of this film record can be selected and made into a loop, so that when it is projected the same series of movements and sounds is presented to the student over and over again. This method has the great advantage that sound sequences can be broken down into their component parts, or into isolated sounds when necessary, and these can be built up again into longer and more complex groups as the student progresses. A series of loops of all the sounds, syllables, words, and sentences which are demonstrated in the film will in due course be available for instructional purposes.

Deaf-mutes quite often have a very small amount of residual hearing which it is important to utilize when teaching them to speak. Since the film has a synchronized sound-track, we have a convenient means of presenting an auditory stimulus perfectly synchronized with the visual one. It is only necessary to take the signal from the sound track, to amplify it and feed it into a pair of headphones, and we have a hearing aid for each patient. Any hearing he may have is thus utilized.

Note. The colour plates, figures 6, 7, 8 and 9, demonstrating the action of the tongue for certain sounds during speech, were selected from a series of photographs made by means of a gas discharge lamp giving an exposure time of a fraction of a millisecond. Figures 1, 2, 3, 4 and 5 are enlargements taken from the normal-speed 'Technicolor' film, each exposure being of the order of 0·02 second.

FIGURE 6 – *View showing the tongue arched towards the front of the mouth for the vowel in* he.

FIGURE 7 – *The tongue lowered and retracted for the vowel in* harm.

FIGURE 8 – *The tongue-tip makes a forward contact for* t *in* part-time.

FIGURE 9 – *In the* k *of* black-case *the tongue is arched and retracted to make contact with the soft palate.*

Giant nerve-fibres

J. Z. YOUNG

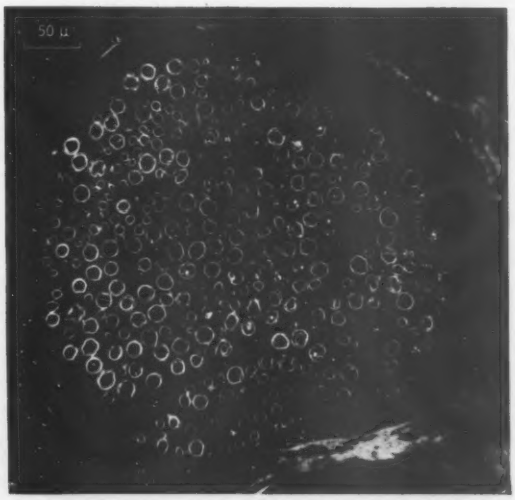
Certain transparent tubular structures in the squid were at first supposed to be blood-vessels. Mr. Young discovered that they are in fact giant nerve-fibres, and the discovery has led to important advances in our knowledge of the nature of nerve-substance and its activities. Of particular significance and value is the light it has shed upon the regeneration of nerves after injury, a subject of especial interest in times of war.

The nerves in the arms or legs of a man are shining white strands containing thousands of nerve-fibres, each one of which is only a few microns[1] in diameter (figure 1). Their function is to conduct sensory messages from the skin to the brain and motor messages back from the latter to the muscles. Each nerve-fibre conducts messages concerned with a single function only; thus there are separate fibres concerned with each of the various types of sensitivity in the skin (touch, warmth, cold, pain) and other fibres responsible for producing contraction of the muscles. Where any delicate functions, involving detailed sensory discrimination or fine movements, are concerned, very numerous nerve-fibres are necessary. For this reason the nerves in the limbs of man are much larger and contain more nerve-fibres than those of other animals.

In all the nerves of man and other vertebrates the number of fibres is rather large and their diameter small. This has been something of a handicap in investigation of the nature of nervous conduction. However, in some of the invertebrate animals there are nerve-fibres of much larger diameter. In 1933, while investigating the nervous system of the squid, I noticed certain transparent tubular structures of about a millimetre in diameter. At first I took them to be blood-vessels and paid little attention to them, but the peculiarities of their microscopic appearance gradually persuaded me that they were nerve-fibres, of a diameter several times greater than that of any others known. It was obvious that if this were so they would provide magnificent opportunities for experimental work, but first it was necessary to study their structure, connections, and functions and to show that they really were nerve-fibres.

The squid is a very common marine animal, related to the octopus. It is caught in large numbers by fishermen in many parts of the world, but a considerable difficulty in working with squids is that they are very active and need a large volume of water. It is therefore impossible to keep them alive away from the sea and even hard to bring them ashore alive, since they are easily damaged in a trawl. However, thanks to the co-operation of Dr Stanley Kemp and his staff at the Laboratory of the Marine Biological Association at Plymouth, supplies of live squid were made available. It was possible to prove that these structures are in fact enormous nerve-fibres, and that they are very suitable for experimental purposes. During the years before the war numerous investigators made use of them, at Plymouth and at the marine station at Woods Hole, Mass., and it was found possible to investigate several properties which could not be studied with smaller fibres.

FIGURE 1 – *Photograph of cross-section of a portion of a mammalian nerve, showing fibres of all diameters from 20 μ downwards. (Photograph kindly supplied by Dr F. K. Sanders.)*



[1] 1 micron (1 μ) = $\frac{1}{1000}$ mm., or $\frac{1}{25000}$ in.

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These large nerve-fibres are used by the squid for its peculiar method of propulsion, which is on the rocket principle (figure 2). A jet of water is squirted from a sac-like organ, the mantle, through a tube which can be directed forwards, backwards, or sideways. The squid uses this mechanism for sudden quick darts through the water, while for more delicate movements it possesses a pair of fins.

The jet is produced by circular muscles whose contraction makes the whole sac smaller. These muscles contain tens of thousands of separate muscle-fibres, but they are worked by only ten nerve-fibres, which are large and graded in size, the hindmost and longest being also the largest. Investigation of one of these nerves confirms that the single large nerve-fibre controls all the muscle-fibres in the hind part of the sac. After the large fibre has been pricked, or otherwise damaged, electrical stimulation no longer produces the quick contractions of the muscle [13]. This demonstrates decisively that the structures in question are nerve-fibres. To produce an effective jet the sac must contract as a whole, and this is ensured by having few and large nerve-fibres, leaving little provision for the performance of graded contractions. The movements of the fins, on the other hand, being delicate, require many nerve-fibres. As figure 3 shows, the nerves here contain numerous small fibres, besides the single very large ones.

Like all nerve-fibres, these giant ones show electrical changes during their activity. It has long been known that as a nerve-message travels the active region becomes electrically negative to all neighbouring regions. Two electrodes placed on a nerve and connected with a suitable amplifying and recording device will therefore register a diphasic change as the impulse passes each electrode in turn (figure 6). It is obviously of great advantage to be able to study these changes in a single nerve-fibre, but with the small fibres of vertebrates this can be accomplished only by the use of a very special technique. In the squid it can be done much more satisfactorily, and without any elaborate preparation, by simply removing the nerve from the animal, laying it on electrodes connected with an amplifier, and applying some stimulus at one end. The potential developed by the activity of the large fibre is so much greater, and is conducted so much faster, than that of the others that it stands out conspicuously (figure 6). Figure 7 shows the record of a series of such impulses which Dr H. K. Hartline and I recorded at Woods Hole. In this case the nerve was activated by applying a solution of sodium citrate to one end; this precipitates the calcium and initiates a rhythmical discharge. In normal functioning, only one such impulse passes over the giant nerve-fibre for each single contraction of the mantle sac.

Many investigators have taken advantage of the ease with which the electrical activities of these squid nerve-fibres can be recorded for further investigation of the propagated impulse. The nature of nervous conduction has of course been studied for many years, and we already have perhaps more information about it than about any other bodily function. The great simplification produced by working with readily accessible large fibres has not only allowed direct confirmation of previous deductions but has made possible the investigation of many new aspects of the process.

It has long been supposed that an essential feature of nerve is that there is a potential difference, the resting potential, between the inside and the outside. This has been confirmed directly by investigations such as that of Hodgkin and Huxley [7], in which an electrode was inserted inside the giant nerve-fibre. The potential difference arises from the fact that the nerve surface is composed of a differentially permeable membrane which, together with the chemical changes going on inside the cell, leads to an unequal distribution of charged particles. In particular, it has been suspected that potassium is present in much greater quantities inside than outside nerve-fibres. This has now been proved by direct analysis of the uncontaminated squid fibres. The actual difference is considerably greater than had been estimated, making various assumptions, from analysis of whole nerve trunks. Webb and I at Plymouth [12] found a concentration of potassium inside the fibres twenty-nine times as great as that outside, and Bear and Schmitt [1] at Woods Hole found a figure of twenty-six times. Sodium and chlorine, on the other hand, are present in smaller amounts within the fibres than around them. If we assume that the membrane is almost impermeable to anions and to the larger cations such as Na^+, but fully permeable to K^+, then the magnitude of the potential should be given by

$$\mathcal{E} = \frac{RT}{F} \log_e \frac{[K^+] \text{ inside}}{[K^+] \text{ outside}}$$

This was calculated for each of the fibres which we analysed and compared with the actual

potentials which had been recorded from the fibres before analysis. The observed potentials were on the average 7·5 mv. below the calculated ones, a discrepancy of about 10 per cent. Considering the difficulties involved, this provides a strong indication that the potential is a potassium diffusion potential. However, this cannot be more than a part of the whole story, if indeed it is correct at all. Steinbach and Spiegelman [11] have recently shown that sodium can enter and potassium leave the fibres quite readily, so that evidently the diffusion potential hypothesis will not cover all the facts.

During the passage of the nerve-impulse the membrane becomes freely permeable to all ions and a current flows between the active and neighbouring regions, causing breakdown of the membrane of the latter, so that a wave of discharge sweeps over the fibre. Dr Cowan of University College, London, showed some time ago that during this process potassium leaks out of the nerve-fibres. Evidently the characteristics of the membrane at rest and in activity are of fundamental importance, and K. S. Cole and his colleagues have now been able to measure the membrane characteristics directly, by inserting electrodes inside the nerve-fibres [3]. They find that the electrical properties of the membrane are equivalent to those of a circuit containing a capacity shunted by an inductance and a rectifier in series. This effect is to be expected in a membrane with selective permeability separating two electrolytes; and Cole suggests a quasi-crystalline, piezoelectric structure for the membrane, as an explanation of the inductance. Hill [6] has shown that the heat evolved during passage of an impulse is smaller than the free surface energy of an oil-water interface, such as is probably involved. We still know too little to be certain of the actual changes which occur, but Danielli [4] has produced a theory based on the assumption that the increase of permeabilities is due to an alteration in the closeness of packing of the molecules, which would result in an evolution of heat of the order of magnitude of that which Hill observed.

One of the most remarkable characteristics of modern biology is the way in which various techniques contribute to understanding of living activities. The old distinction between structure and function breaks down, and we find that information obtained with various optical and other physical and chemical techniques all converges to give us an idea of the living processes. This has been conspicuously true in the case of nerve-fibres. Besides the electrical studies mentioned above, there have been optical investigations of the fibre in ordinary and polarized light, showing the presence of a longitudinal organization in the molecules of which the nerve-fibre is composed [2]. By squeezing out the contents from the end of a dissected giant fibre, about 10 mg. of pure 'axoplasm' can be obtained; and with such material, besides the analyses of potassium described above, investigations of the nerve-proteins have been made. Recently Richards and his colleagues [10] have studied further details of the fine structure with the electron microscope, finding rodlets of all sizes from 15 mμ upwards.

This information about the nature of nerve and its conduction enables us to understand much more about the factors which determine the velocity of the nerve-impulse. In a system such as has been described the conduction velocity should be increased (*a*) by increasing diameter, giving lowered internal resistance; and (*b*) by changing the characteristics of the membrane. The latter method is that which has been adopted in vertebrates, where each nerve-fibre is surrounded by concentric layers of orientated fatty molecules making the 'myelin sheath.' In the squid no such thick layer is present, but since there are nerve-fibres of diameters varying between 1 μ and 1 mm. this animal is ideal for investigation of the effect of diameter. Actually it is not easy to use quite the full range of fibre diameters, but Pumphrey and I [9] found that rates of conduction varied between 3 and 22 metres per second with diameters from 40 to 718 μ. The rate appears to follow approximately the square root of the diameter, a result which agrees with some theoretical expectations.

From these results it is also possible to see the value to the squid of a series of nerve-fibres of graded diameter. If all the fibres conducted at the same rate, the front end of the sac-like mantle would close before the hind. Actually the conduction-rates in the nerve are so adjusted that contraction of the whole sac occurs nearly simultaneously. The presence of giant fibres also significantly lessens the time taken by the animal in getting under way. Rapid conduction is very necessary for an active life, especially in a long animal. The conduction-rate in the largest nerve-fibres of the squid is about 25 metres per second, whereas in the smaller, numerous fibres, such as those innervating the fins, it is not more than 5. Probably it takes the animal not longer than 50 msec. to get under way after some attractive

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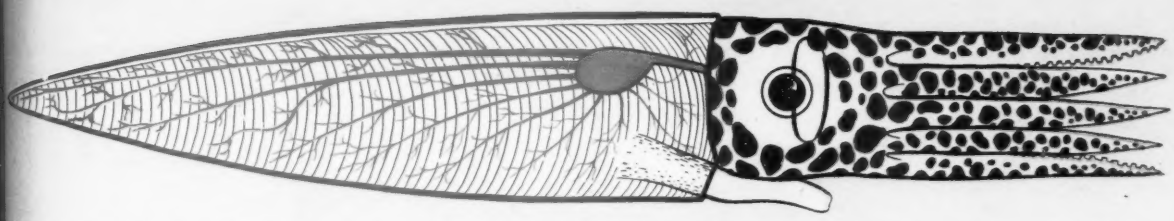

FIGURE 2 – *Diagram of a squid with the mantle-sac cut open to show the stellate ganglion (pink), from which emerge ten nerves each containing a giant fibre (red). The fibres increase in size posteriorly, and as the conduction-rate increases with the diameter the nerve impulses reach all parts of the mantle-sac at about the same time.*

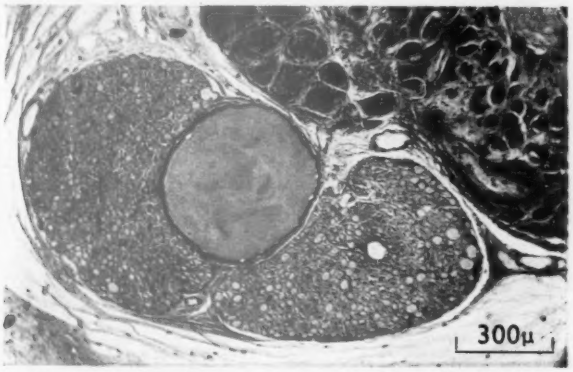

FIGURE 3 – *Photograph of transverse section of one of the stellar nerves of the squid as it is leaving the ganglion. One very large fibre is seen, surrounded by a sheath of collagen stained green. The remainder of the nerve is made up of numerous small fibres. Above the nerve is seen a portion of the ganglion, the Nissl substance, characteristic of nerve-cells, being stained purple. Section stained with Masson's trichrome method.*

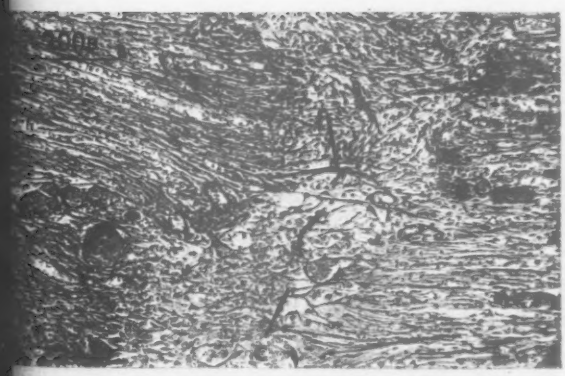

FIGURE 4 – *Longitudinal section of a nerve which had been cut five days previously and the ends then brought together. The central end lies to the left and contains nerve-fibres from which new processes (f) are growing out into the damaged region. Here they meet special columns of cells (c) which grow out from the peripheral stump to meet them. This and the next figure are of preparations stained with Bodian's silver stain for nerve-fibres and Masson's trichrome stain. The nerve-fibres are black or purple-brown, blood-vessels orange, connective tissue green.*

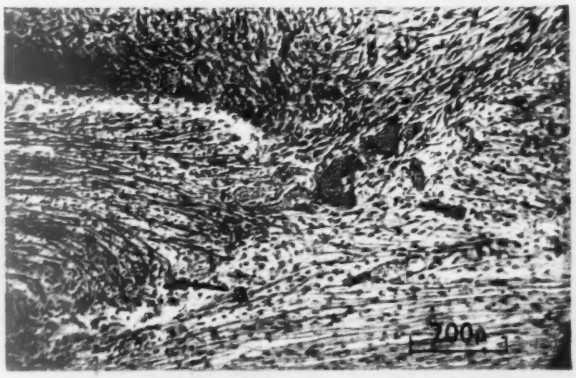

FIGURE 5 – *Longitudinal section of a rabbit's nerve which had been cut five days previously and the ends not properly joined. The central end lies to the left. New material (a) is growing out from its nerve-fibres, but is blocked and unable to connect with the peripheral stump.*

FIGURE 6 – *Record of action potential in nerve of a squid. The nerve has been laid across electrodes, two for stimulation and two connected with an amplifier. The record reads from left to right. The first oscillation is produced by the application of the stimulus, the second by the giant fibre, and the subsequent ones by the combined effect of the smaller fibres in the nerve. The time-signal marks indicate* 10 *msec.*

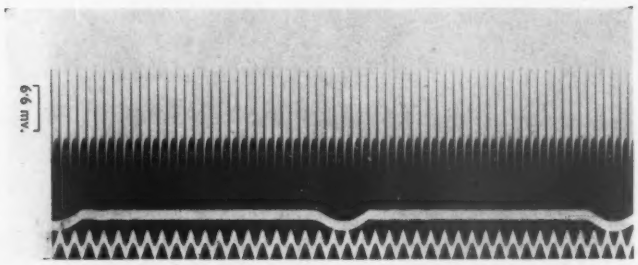

FIGURE 7 – *Record of repetitive discharge in giant fibre of a squid to one end of which a* 1 *per cent. solution of sodium citrate has been applied. The time-markers show* 10 *and* 200 *msec.*

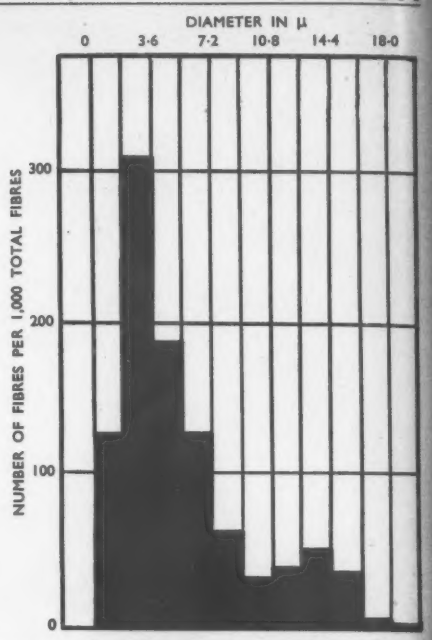

FIGURE 8 – *Histogram to show the numbers of fibres of different sizes in a motor nerve of a rabbit. (Figure kindly supplied by Dr F. K. Sanders.)*

or unattractive picture has fallen on its retina. Of this time only about 15 msec. is occupied by conduction along the nerve-fibres, so that if these were small, and conducted at, say, 5 metres per second, the animal would take at least twice as long to start.

The giant squids such as *Architeuthis*, which live in the depths of the sea, are much larger than the common forms (*Loligo*) which we have been considering. A specimen which had been washed up at Scarborough, and which I examined in the Natural History Museum at South Kensington, had a mantle 125 cm. long, and its total length, including the tentacles, must have been over 2 metres. Much larger specimens have been recorded. But the nerves of the above specimen contained no fibres larger than 250 μ. There is no reason to think that these conduct any faster than would fibres of the same size in *Loligo*. Moreover, the nerves in the long arms do not contain giant fibres. Therefore it must take at least a second for a message to go from end to end and back in these animals. This confirms certain other evidence that they are rather sluggish creatures, though no doubt very formidable, with their suckered tentacles and beak-like jaws.

Other very elengated animals also make a considerable saving of time by having large nerve-fibres. When an earthworm is touched it withdraws surprisingly rapidly, and the message is conducted by fibres which are about 100 μ in diameter and also have a fatty sheath. Some years ago we were able to show that these conduct at about 25 metres per second, that is to say at a speed reached in the squid, which has no thick fatty layer, only by much larger fibres. Similarly crustaceans, such as the crayfish, have large nerve-fibres to conduct messages to initiate the quick flip of the tail by which they escape.

The constant high temperature which is maintained by birds and mammals increases the speed of conduction to more than 100 metres per second, which means that a message can go from end to end even of the largest whale in a fraction of a second. We can see the advantage of such rapid conduction when we consider that in ourselves, if there were no conduction faster than 1 metre per second, it would take more than a second for the leg to be withdrawn after contact of the foot with a hot surface or pin.

A very interesting point is that the nerve-fibres in any one animal do not all conduct equally fast. In mammals each sensory or motor function is subserved by fibres of a particular diameter. Each nerve thus contains a spectrum of fibres of different diameters and conduction-rates (figure 8).

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The fastest ones, with a diameter of about 20 μ (including a sheath of 5 μ), are those which carry impulses from the central nervous system to the muscles. Speed is probably important here not only because of the time saved but also because it ensures that the contraction of numbers of muscle-fibres shall be nearly simultaneous. The messages concerned with touch are carried at about 25 metres per second. Curiously enough, the fibres dealing with pain are many of them very small and conduct only at about 1 metre per second. Lewis [8] has shown that there are also other pain fibres conducting at a faster rate, and that when the skin is pricked with a pin we can distinguish between the fast pain which comes first, and the later pain arriving in the slower fibres.

This question of the spectrum of fibres present in a nerve brings us to an aspect of work on nerves which is of especial interest in war-time, namely their regeneration after injury. When a nerve has been severed, the nerve-fibres disappear from that portion which has been separated from the central nervous system, leaving in this peripheral stump only the framework of the nerve composed of connective tissues and other elements. The nerve-fibres of the central stump, however, remain intact and soon begin to put out new growths (figures 4 and 5). If the divided ends of the nerve-trunk have been stitched together, these outgrowths from the central fibres grow down into the peripheral stump and ultimately reach the muscles or skin. But we have seen that a large nerve contains thousands of different nerve-fibres, and that these include several groups having different diameters, conduction rates and functional connexions. If proper regeneration of function is to take place, appropriate new connexions must be made. Motor nerve-fibres must join up with muscles and not with skin and so on. It has often been suggested that special forces of attraction are at work ensuring the correct connexions. But recent work in this department and elsewhere has shown that the connexions of the two stumps are made at random. Each of the (say) ten thousand fibres in the central stump divides and puts out numerous branches, and these grow down whichever tube in the peripheral stump they happen to contact. Many wrong and some right connexions will be made in this way, and it is possible that there is some mechanism by which the incorrectly connected fibres are later removed.

Study of the diameter of the newly formed fibres in the peripheral stump shows that it approaches only very slowly towards normal. Even in so small an animal as the rabbit the process is not complete one year after a nerve has been sutured, and the spectrum of fibre sizes probably never again becomes normal [5]. It is no wonder that after severance of a nerve the return of function is never completely satisfactory. Muscle movements remain poorly co-ordinated and there may be abnormal pains and other sensations. The more we know of nerve conduction and regeneration the more likely we are to be able to prevent or correct these disabilities. The very fact that the body provides even a very slow mechanism for regeneration after injury shows the fundamental importance of the nerves. It is satisfactory that we know something about them, but all this is only a beginning, and we may hope that some day it will be possible to give a much more complete account of the forces at work in nervous conduction and regeneration.

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Artificial cooling and its vital services

JAMES SMALL

As applied to the preservation of food, and its successful transportation over great distances, mechanical refrigeration has effected a great and lasting economic revolution. Professor Small sketches in non-technical language the development of this aspect of artificial cooling, which in time of war is of literally vital importance and which in the years of peace to come will bring men easement and health. Much of the fundamental work was British.

The process of cooling, if it is a planned and deliberate action, is artificial no matter how simple the means may be by which the aim is achieved. For 'artificial cooling' we may substitute the term 'refrigeration,' which, properly applied, means the process of cooling to any temperature below our common experience, whether it be below the freezing-point or not.

THE EARLY ARTS OF COOLING

The early civilizations were all located in countries in which the warmth of the sun was often a burden. The ancients had therefore a greater appreciation of coolness than we in Britain have much reason to acquire, and we may well believe that they were willing to go to a great deal of trouble even to enjoy the refreshment of a cooling drink—as indeed they were. In the winter season snow was collected where it could be found, compressed to a solid block of ice, and carried, sometimes over long distances, in simply insulated containers to be stored in cellars for use in the hot season. There is evidence that this practice existed among the early Chinese, the Jews, the Greeks, and the Romans.

A cool drink was usually obtained by melting a piece of ice in the beverage itself. But there were no rules of hygiene observed in the collection or the storage of the ice, and the Romans became aware that a great deal of illness arose from indulgence in cooled drinks. To avoid this they resorted to the cooling of beverages from outside the container. In other words they introduced the idea of the ice-pail or the champagne-cooler. This innovation is, surprisingly enough, attributed to the Emperor Nero, who as a student of natural phenomena is usually accredited with an interest in combustion rather than refrigeration.

THE BEGINNINGS OF THE SCIENCE OF COOLING

The marked degree of cooling which follows the blowing of air upon a surface which has been wetted by a liquid more volatile than water is a matter of long-standing experience, and was for many years used by physicians as a means of obtaining local anaesthesia.

The basic work in this field was done in the College of Glasgow about two hundred years ago by the great physician William Cullen, who was its first lecturer in chemistry. He demonstrated that the boiling-points of liquids vary with pressure, and that cooling may be effected by promoting evaporation through a reduction of pressure. In an essay written in 1755 Cullen says:

> In an experiment made with nitrous aether, when the heat of the air was about 43°, we set the vessel containing the aether in another, a little larger, containing water. Upon exhausting the receiver [in which the vessels were placed] and the vessels remaining for a few minutes *in vacuo*, we found the most part of the water frozen and the vessel containing the aether surrounded with a thick and firm crust of ice.

So far as is known this is the first record of the production of ice by artificial means. It was Cullen's pupil and successor, Joseph Black, who formulated the theory of latent heat. In doing so he made a major contribution to the science of refrigeration.

DEVELOPMENT OF MECHANICAL REFRIGERATORS

No attempt to embody Cullen's experiment in a commercial machine was made until about the year 1834, when Jacob Perkins built a compression refrigerator to use a volatile liquid as a working substance. Had he persisted in his original intention of using 'sulphuric ether' he might well have had the first successful ice-making machine to his credit, for his apparatus had all the essential features of the practical vapour-compression machines of the present day.

The first continuously acting machine was perhaps one invented by Dr Gorrie of New Orleans

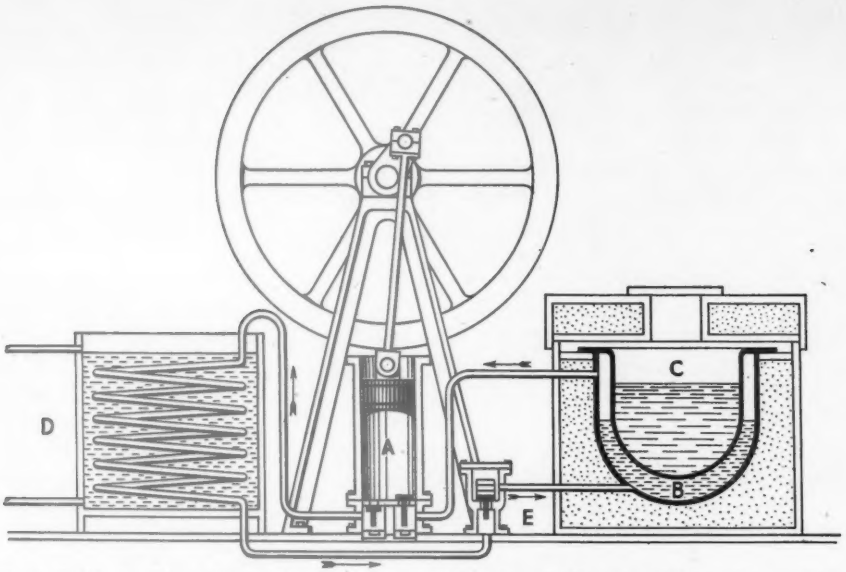


FIGURE 1 – *Jacob Perkins' refrigerating machine, 1834. It had all the main features of the modern machine. The compressor* A *drew the vapour from the volatile liquid in the space* B*, causing heat to be extracted from the water and ice to be formed in the vessel* C*. The compressed vapour passed to the condensing coil* D *in which it was liquefied. Thereafter it passed through the expansion valve* E *back to the space* B.

(*a*)

(*b*)

FIGURE 2 – (*a*) *Quick freezing. Muscle structure in meat frozen completely in* 4 *minutes.* (*b*) *Slow freezing. Muscle structure in meat in which freezing has taken* 275 *minutes. For this purpose the period of freezing is the time taken to bring the temperature from* 5° *C to* — 5° *C.*

(From *Food Investigation Reports of the D.S.I.R.*, 1931.)

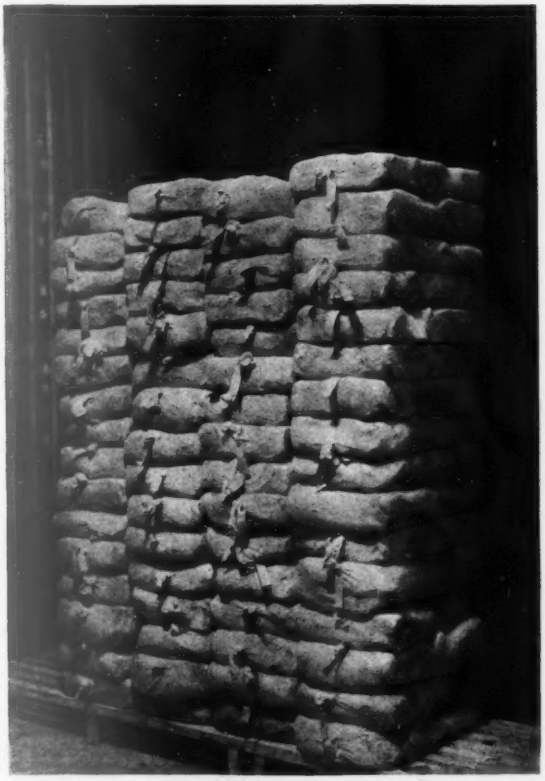


FIGURE 3 – *Slabs of quick-frozen boned beef prepared in England for shipment to war zones. These* 64 *slabs weigh* 2,009 *lb. and occupy* 37½ *cu. ft. A single carcase in the ordinary form weighs about* 700 *lb. and has up to* 100 *cu. ft. allotted to it. Thus shipping space is saved by boning, compressing, and quick freezing.* (*By courtesy of* Modern Refrigeration.)

about 1845, the working substance being air; but because of its very uneconomical performance, arising from mistakes of a thermodynamic nature, it was not a marked success. James Harrison, an Australian, made a success of an ether machine in 1857, and Alexander Kirk about 1860 constructed, for work connected with paraffin extraction from shale distillates in Scotland, a practical air-refrigerating machine.

In the seventies much progress was made, largely because the thermodynamic principles underlying the process, which were established about 1850 by William Thomson (Lord Kelvin) and Macquorn Rankine, had then become more widely appreciated. It is not possible to sketch here in detail the many advances arising from the introduction of ammonia and carbon dioxide as working substances, and from the development of the method of the absorption and disassociation of the volatile substance to replace the compressor. Much credit is due to workers in continental Europe, such as the brothers Carré, Windhausen, and Linde.

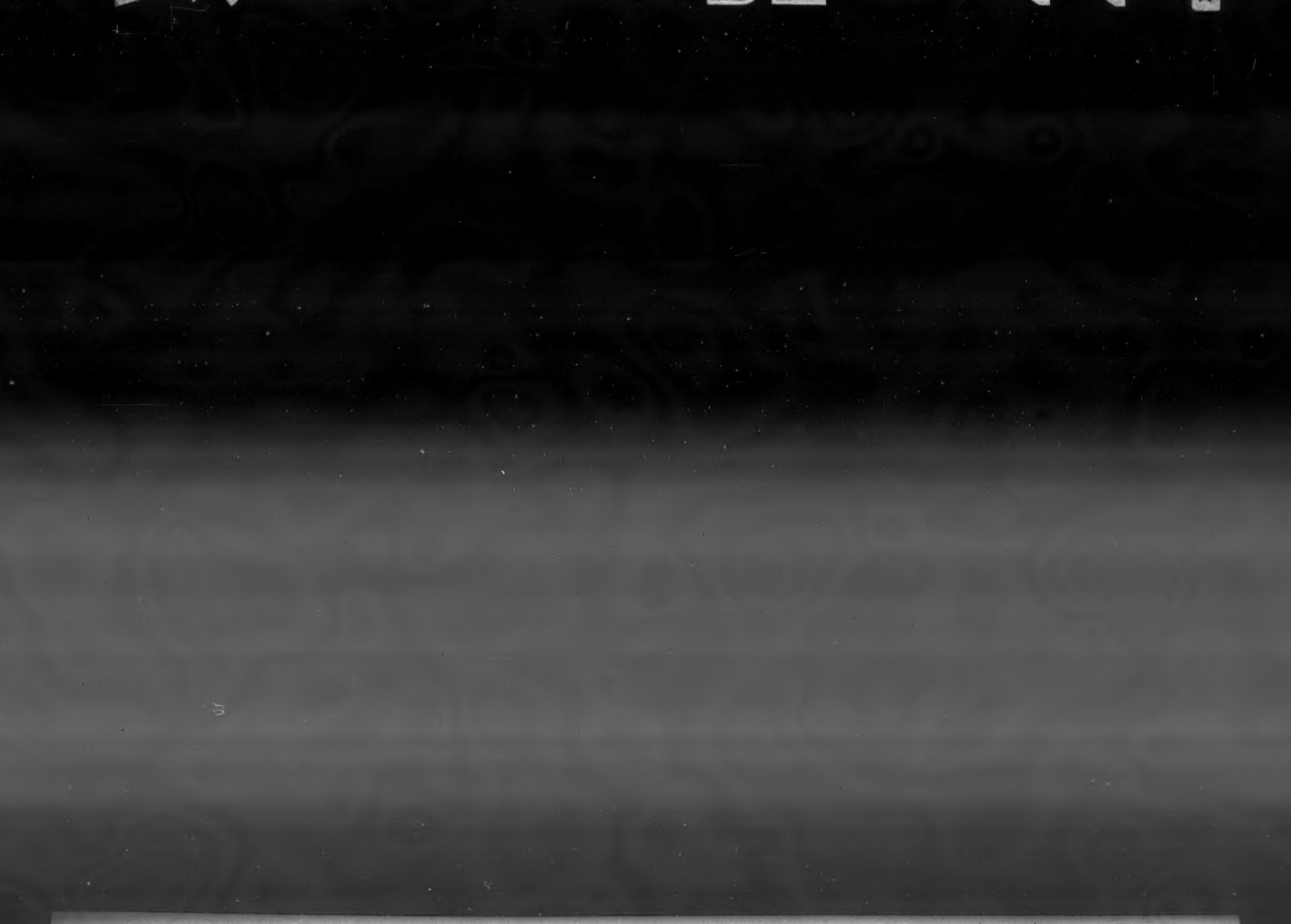
USE OF COLD IN FOOD PRESERVATION

It was known long ago that if food is kept cool its edibility is prolonged. It is recorded of Francis Bacon that in March 1626, when driving near Highgate, he was taken with a desire to discover whether snow would retard putrefaction. He stopped his carriage, bought a fowl, and, with his own hands, stuffed it with snow. It is not known how the experiment went; but the result, it would seem, was disastrous to the experimenter, who died of a chill a week or so later.

The idea was not new. According to authorities, ancient Roman cookery-books have references to the covering of certain dishes with snow, the object of which could only have been preservative.

The use of the ice-box in preserving foods is no doubt very ancient, and the method is still widely used today. The first perishable foodstuff ever transported over a lengthy sea route was meat, which was preserved on board ship by means of ice mixed with salt and packed round the containers. At a later period, ice-cooled air was circulated in the meat chambers. This was in the 'seventies of last century, when the only import trade in chilled beef was from the United States to Britain. An early attempt to bring meat from Australia by this means was a failure. For such a lengthy voyage something more lasting than ice was needed. In 1877 a French ship carried a perishable cargo from the Argentine to France with fair success, although the voyage took 110 days. The ship carried an ammonia type of refrigerating machine on board.

FIGURE 4 – *A corner of a cargo chamber in a ship. The great system of pipes carries brine, which itself has been cooled to a low temperature by the refrigerating machinery.*
(By courtesy of L. Sterne & Company Limited.)



DEVELOPMENT OF BRITISH MARINE REFRIGERATION

We may assume that the experience of the ammonia machine had not been a happy one—as indeed it was not likely to be in the state of refrigerating engineering at that time—for the French abandoned the experiment and the field was left open.

Henry and James Bell, members of a firm of meat importers in Glasgow, were anxious to adopt some form of mechanical refrigeration on the ships carrying their cargoes, and consulted Lord Kelvin, who brought in James Coleman, a chemist who had experience of refrigeration in the shale industry. The upshot was the making of the Bell-Coleman cold-air machine, which was installed in the Anchor liner *Circassia* in 1879. She plied between New York and Glasgow, and the success of the venture may be taken for granted, for a second machine was fitted in the *Strathleven*, a steamer of 2,257 tons, which in 1880 brought 34 tons of frozen mutton and beef from Australia to London. A sailing ship, the *Dunedin*, fitted with the Bell-Coleman refrigerator, in 1882 brought the first 5,000 frozen carcases of mutton from New Zealand. Expansion of this trade was rapid. In the year 1874, by the old ice-box methods, 55 tons of meat were imported. In the year 1901, with the aid of refrigerating machines, 150,000 tons were imported from the United States alone, and in one month of 1939 a total of 90,000 tons of meat was brought in from all sources.

A similar trade in imported fruit sprang into existence, and developed rapidly when the technique of the proper care of fruit in storage had been worked out.

ECONOMIC RESULTS

The outcome of these new developments was startling. It led to an economic revolution, and Australia, New Zealand, and South America began to build up great economic strength. But the effects in the international field were not unaccompanied by unsettlement at home. A factional war was waged between opposing vested interests—the home producers of meat on the one hand and the importers on the other. An interesting light is thrown upon public feeling at this time by cartoons in *Punch*, which in the 'eighties still retained its early Radical complexion.

It may be accepted, with little qualification, that, without the import of refrigerated foodstuffs, a country like Britain could not at any time maintain its population of factory workers. British economic stability depends on refrigeration and, in time of war, so also does the national security.

Since 1880 standards of diet and the amenities of life have greatly improved. By the application of artificial cooling, fruits, for example, that were exotic and rare have, except for the interruptions of war, been made available to the masses of the population in Britain.

Let us try, for a moment, to forget our present somewhat unvaried menu and view dispassionately the peace-time record of marine refrigeration. In the month of January in the year 1939 Great Britain imported enough meat to give every man, woman, and child a weight of four pounds, enough butter to give everyone a pound and a half, enough oranges to give everyone a dozen, and, in addition, large quantities of eggs, bananas, grape-fruit, lemons, grapes, pears, plums, peaches, and apples.

The saving of perishable foodstuffs by cold storage on land stands in importance second only to marine refrigeration. This is of course especially true in time of war, and the Government has added to the nation's normal cold storage space by erecting in different parts of the country great refrigerated stores, which are possibly the best of their kind to be found anywhere.

COLD STORAGE TECHNIQUE

The solution of the mechanical problem of refrigeration was far from being the end of the matter. Alongside the engineer have worked the biochemists and bacteriologists, in the study of the behaviour of foodstuffs under different physical conditions. The work of the late Sir William Hardy, who had the combined attributes of the engineer, the chemist, and the biologist, gave to Great Britain the honour of leading the way in the comprehensive and scientific study of food preservation. His work with the Food Investigation Board at the Cambridge Low Temperature Research Station and elsewhere has become classical, and has inspired researches of inestimable value.

THE STORY OF THE APPLE

An example of the achievements of Hardy and his associates is the research on the behaviour of the apple in storage. Cargoes of apples carefully packed and kept at a temperature sufficiently low to retard the process of decay, though not to freeze them, were found at the end of a lengthy voyage to be unsalable because of brown-heart disease. Investigation of this effect led to an

explanation which may be summarized as follows:

The apple, like all fruits, is a living organism, and its living processes do not stop when it is taken from the tree. It inhales oxygen and exhales carbon dioxide and water. The faster the respiration the shorter the time of ripening; the slower the respiration the longer the fruit will keep. Cold retards the life processes, but so long as respiration goes on, the atmosphere in which the apple lives is of importance. With carbon dioxide in the air up to a concentration of 12·5 per cent., the processes are slowed down and the time for which the fruit will keep in store is lengthened; but at higher concentrations the life flickers and disease takes its toll. Hence ships' holds in which apples are carried must be ventilated in such a way as to check the accumulation of the carbon dioxide exhaled by the apples themselves.

Freezing of apples is avoided in sea transport. Their freezing-point is about 29° F and they are usually held at about 31° F. Like all other substances containing water, apples lose weight if the relative humidity in the cold storage rooms is below a certain level.

COLD STORAGE OF MEAT

Meat kept at a temperature just above its freezing-point is called chilled meat. It does not as a rule keep for more than about 28 days, but up to that period it looks like fresh meat when exposed for sale. Frozen meat, on the other hand, is meat cooled to about 15° F; it remains edible for long periods. Following the experience with fruit, carbon dioxide was tried in the atmosphere of rooms containing chilled meat, and the experiment was a marked success. The keeping quality was greatly improved and the growth of moulds was largely inhibited. Previously, meat could be brought from so far away as Australia and New Zealand only in the frozen condition, but now, with the new 'gas storage' method, it can come as chilled meat.

EFFECTS OF SPEED OF FREEZING

When frozen meat is thawed it often exhibits the unpleasant feature called 'drip.' This may arise to some extent from the simple phenomenon which causes our water-pipes to be ruptured in a time of frost, but that is not quite the whole story, since the walls of the cells of the meat are elastic. If the rate of freezing is very slow, the ice crystal inside a cell may be enlarged by liquid diffusing through its walls from the outside until the walls are torn by the growth. On thawing, the juices run out. If the freezing is carried out very rapidly, however, by the application of a very low temperature, the unattractive 'drip' is found to be absent when the meat is thawed. This discovery has led to the application of methods of quick freezing to fish, meat, fruit, and vegetables, for with proper care the thawed foodstuff is found to be as fresh and pure, and to have the same natural flavour, as before storing.

The speed of freezing of beef is greatly increased by boning it, packing it into slabs, and compressing it between hollow freezing plates to which the low-temperature refrigerant is applied. This procedure is largely displacing chilled meat because of the great economy in shipping space effected.

EGGS AND OTHER THINGS

We have seen how fastidious the apple may be as to its conditions of storage, but the egg—though today we have reason to view it with respect—has always seemed to be rather dull and unresponsive. Yet the egg is the most temperamental of foodstuffs for the cold stores to handle.

Even a healthy egg when alive gives off gas, and if this is not continuously removed, fungus forms and the egg becomes musty. If the humidity of the atmosphere is not just right, it may, on the one hand, lose weight or, on the other, grow whiskers of mildew. And the temperature must not deviate by more than a narrow margin from 32° F. Eggs cannot be stored with other things, for they are susceptible to taint from the slightest odour. The greatest care must therefore be taken that they are stored by themselves in rooms which are not adjacent to others used for storing fruits and other produce. Butter must be kept in the dark if it is not to deteriorate in both colour and flavour. Every one of the innumerable kinds of perishable produce has its own whims and peculiarities.

CONCLUSION

The description of the many applications of mechanical refrigeration to matters other than the preservation of food must await another occasion. Sufficient has been written here to show that the engineer and chemist have in the development of refrigeration been responsible for a greater and more lasting revolution than any political figure or great dictator in history. And it has been a revolution which is bringing to men in ever-increasing measure easement, and sweetness, and health.

Thomas Charles Hope, 1766—1844

JAMES KENDALL

From the science of our schooldays, a few experiments are apt to be recollected with sharp clarity. One of them is Hope's experiment to determine the temperature of the maximum density of water. Perhaps it was not so much the elegance of the procedure as the extravagance of using two thermometers at the same time that impressed us. In any case, Hope 'springs eternal' in our memories, and Professor Kendall tells us what manner of man he was.

This year marks the centenary of the death of Thomas Charles Hope, F.R.S., Professor of Chemistry at the University of Edinburgh from 1795 to 1844. Though his fame is somewhat overshadowed by the superior achievements of his predecessor Joseph Black, Hope ranks as a noteworthy contributor to the progress of science. He was the first teacher in Great Britain to substitute the new doctrines of Lavoisier for the phlogiston theory in his public lectures; he isolated and named the first known compound of strontium; he first established the exact point of the maximum density of water; and he recommended Humphry Davy to the notice of Count Rumford as a suitable lecturer for the Royal Institution.

Hope's father was Regius Professor of Botany in the University of Edinburgh, and he himself entered as a student there at the precocious age of 13. As was natural, he devoted much attention to botany, and displayed such proficiency in this science that on his father's death in 1786 he was put forward as a strong candidate for the vacant chair. This was in accordance with the practice of the times, since for a record period of 126 years the sister professorship of anatomy was occupied by Alexander Munro (three successive generations, 1720–1846), but the young man of 20 was forced to wait another year before he was selected to fill a responsible academic position, the lectureship in chemistry at the University of Glasgow.

He was then, like his teacher in Edinburgh Joseph Black and all his British colleagues, a strenuous supporter of the phlogiston hypothesis of Stahl. His friend Sir James Hall, however, returned to Scotland in the autumn of 1787 from Paris, where he had been much in the society of Lavoisier, who exhibited to him several very important experiments not yet made known to the chemical world in general. Hall had many long discussions on the work of Lavoisier with Hope, and soon convinced him of the truth of the new ideas. That winter he taught them to his class, the first occasion on which the doctrines of Lavoisier were publicly promulgated in this country, and the following summer he himself spent in Paris, where the amiable manners and great abilities of Lavoisier made a strong and lasting impression upon him. As his biographer [8] remarks: 'Few persons more sincerely deplored the sad fate of that accomplished man, from whom he had received the most flattering attentions.'

In 1789, Hope obtained the appointment of assistant professor in medicine to his uncle Dr Stevenson in the University of Glasgow, and on the death of his uncle in 1791 became the sole Professor of Practical Medicine. He then resigned the office of lecturer in chemistry, but continued his private researches in his favourite study, the first result of which was a masterly paper on a mineral from Strontian, communicated to the Royal Society of Edinburgh in 1793.

In this article [1] Hope proved, what had been previously only conjectured by Crawford and others, that this mineral contained a peculiar 'earth,' differing decidedly in properties from barytes, with which it is associated. To this new earth Hope gave the name of *strontites*, from the village of Strontian, in Argyllshire, Scotland, at which it had been found. His original preparation (dated 1791) of what is now known as strontium hydroxide still stands in the museum of the department of chemistry at the University of Edinburgh: a clear saturated solution with a fine crop of crystals at the foot, as shown in figure 2. Several other chemists have claimed the credit for the discovery of strontium (the metal itself, it may be noted, was first isolated in 1808 by Humphry Davy), but critical examination of the literature justifies the statement of Traill [8]:

> The only chemist who has the slightest claim to the merit of an original detecter of Strontium earth, besides Dr Hope, is M. Klaproth, who, in the

Chemische Annalen for 1793–94, compared Strontianite with Witherite. Neither Klaproth nor Hope seems to have been aware of what the other had discovered, and both may therefore be considered as original discoverers, but the first full investigation of the subject is undoubtedly due to Dr Hope.

This brilliant research, and the popularity of Hope's chemistry teaching at Glasgow, suggested to Joseph Black, then in declining health, the idea of securing his promising pupil as his assistant and successor in the chair of chemistry at Edinburgh, and in November 1795 the patrons chose Hope in that capacity. In the following session, Black found it necessary at last to relinquish his long-famous lectures and introduced Hope to his class in the following terms:

> After having, for between thirty and forty years, believed and taught the chemical doctrines of Stahl, I have become a convert to the new views of chemical action; I subscribe to almost all M. Lavoisier's doctrines and scruple not to teach them. But they will be fully explained to you by my colleague and friend Dr Hope, who has had the advantage of having them from the mouth of their ingenious author.

On Black's death in December 1799 Hope became the sole Professor of Chemistry at Edinburgh University.

That position he held for forty-five years. The variety and excellence of his illustrations, and his dexterity in chemical manipulations, made him the most popular teacher of the science that had ever appeared in Great Britain.

> Not only was his lecture-room crowded with medical students from every part of the British dominions, but numerous foreigners resorted to Edinburgh and became his pupils. The large class-room was filled to overflowing, and he who was not there before the commencement of the lecture had no chance of a seat.

That this quotation [8] is no exaggeration is shown by the fact that the average attendance at Hope's lectures increased from 225 at the time of his appointment to 575 in 1827; the total number of tickets issued for his chemical course during his tenure of office was no fewer than 16,800. In 1838, on the completion of his fiftieth year as a professor of chemistry, he was invited by a numerous body of his former pupils to a public dinner, at which he stated that he had never been, either as a student or as a teacher, detained from the duties of his class, except for *six days by indisposition.*

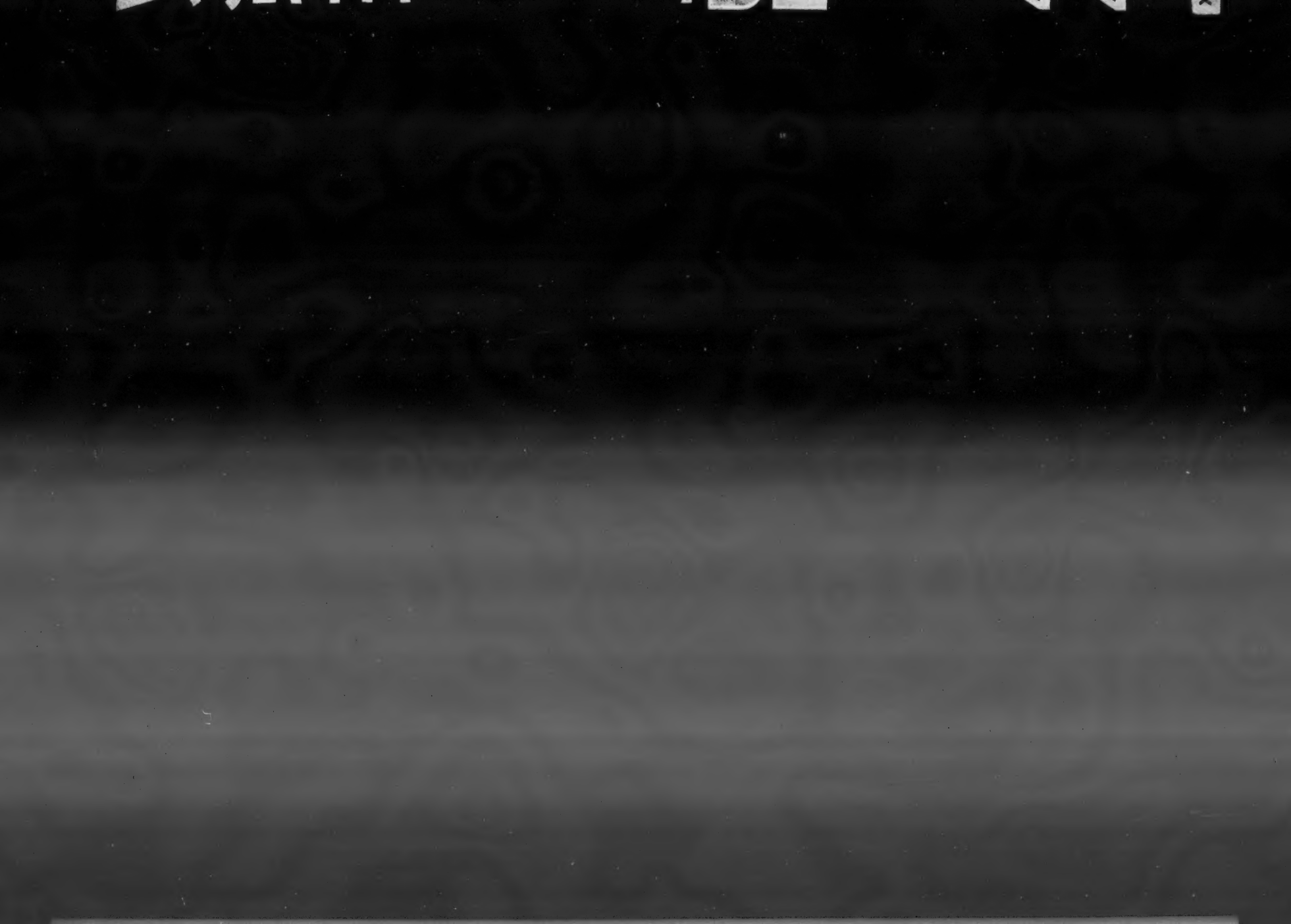
Such scrupulous attention to academic responsibilities inevitably restricted Hope's output of research to a minimum during the period of his prime. He reconciled himself with some regret to this limitation, and among his private papers there was found after his death the following interesting statement:

> Those who devote themselves to the science of chemistry may be divided into two classes. 1st, Those whose labours are employed in original researches, to extend our knowledge of facts and principles. 2dly, Those whose business it is to collect the knowledge of all that has been discovered or is going forward, to digest and arrange that knowledge into lectures, to contrive appropriate and illustrative experiments, and devise suitable apparatus for the purpose of communicating a knowledge of chemistry to the rising generation, or others who may desire to obtain it. From my professional situation I consider myself, *as Dr Black had done before me*, as belonging to the second class of chemists. I consider my vocation to be the teaching the science.

Some time, nevertheless, he did manage to set aside for research. In 1804 he presented an important memoir to the Royal Society of Edinburgh on the contraction of water by heat at low temperatures [2]. As long ago as 1667, the singular fact had been noted by the Florentine academicians that water expands as it cools towards its freezing-point, and Croune had shown this phenomenon to the Royal Society of London in a Gresham Lecture in 1683. Several subsequent investigators had endeavoured to determine the exact temperature at which water attains its maximum density, but could not derive consistent results. All their experiments were made in tubes with large bulbs at one extremity, like huge thermometers.

It was contended by Hooke, after the delivery of Croune's lecture, that the expansion observed was only apparent, not real; arising from the sudden contraction of the material of the bulb on the application of cold. This opinion was still held more than a hundred years later by many eminent chemists, including Dalton, who carried out a series of inconclusive experiments on the phenomenon and finally drew Hope's attention to it in a private letter. Hope settled the question for ever by experiments in which a change in the capacity of the containing vessels could have no influence on the results.

He took a cylindrical glass vessel, 8½ in. deep and 4½ in. wide, which was filled with water at the freezing-point, 32° F. Two delicate thermometers were suspended in the vessel, the bulb of one being half an inch below the top of the liquid and that of the other as far from the



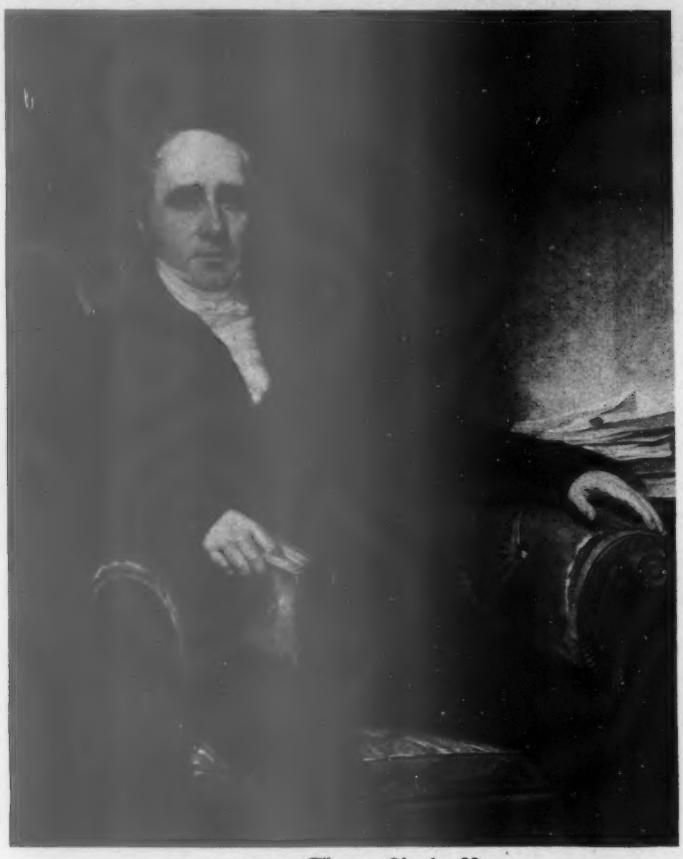


FIGURE 1 – *Thomas Charles Hope.*
(From a painting by Raeburn.)

bottom. The apparatus was placed in a room at a temperature of 60°, and the progressive changes in the temperature of the water were carefully noted on both thermometers. From 32° to 38°, the lower thermometer was invariably higher than the upper; a proof that throughout this interval the water was becoming more dense as the temperature rose. On reversing the experiment by placing water at 53° in an environment cooled to 32°, Hope found that while the temperature of the water was falling to 40°, the water at the bottom was always the colder, but that in cooling from 40° to the freezing-point, the thermometer at the bottom remained higher than that near the surface.

The temperature of the maximum density of water was thus established as lying between 38° and 40°; Hope's final value, after he had varied his technique in different ways, was 39·1°. This is in good accordance with the modern figure of 39·2° F (3·98° C).

Dalton admitted the accuracy of Hope's observations, but a long note attached to the main paper failed to convince Count Rumford that Hope had also demonstrated conclusively the fallacy of his theory that liquids were absolute non-conductors of heat. It is rather strange that Rumford should have hesitated to acknowledge Hope's scientific acumen, since he was directly indebted to him for the discovery of Humphry Davy. Passing through Bristol in 1799, Hope visted Dr Thomas Beddoes, who had been his fellow-student at Edinburgh and was, indeed, one of the original members of the Chemical Society of the University of Edinburgh in 1785 [6]. In Beddoes' laboratory at the Pneumatic Institution, he found the twenty-year-old Davy immersed in his experiments on nitrous oxide, and was deeply struck by his originality and inventive genius. Soon afterwards, Hope was consulted regarding a 'lecturer of talent' required by Rumford for the Royal Institution; he strongly recommended

Davy to the notice of the Count and, in 1801, Davy received the appointment. Never in the history of chemistry was a recommendation more richly justified by subsequent results.

Hope also evidently made an impression on Davy. Unable to realize his own cherished ambition to obtain an Edinburgh degree, Davy sent his younger brother (and future biographer) John to be trained as a chemist in Hope's laboratory. It was there that John carried out a series of decisive demonstrations upon the elementary nature of chlorine to refute the criticisms of Murray on Humphry's work.

In 1826, at the ripe age of 60, Hope emulated Davy's social triumphs at the Royal Institution by instituting 'a short course of chemical lectures for Ladies and Gentlemen.' His vast lecture-room was packed with a most brilliant audience; and he gave the proceeds—a sum of £800—to the Senatus Academicus to establish a prize 'to the author of the best essay on a given chemical subject, illustrated by experiment.' This fund has since been augmented, and five Hope Prize Scholarships are now awarded annually to deserving Edinburgh students of chemistry.

Hope never married. His department was his wife, his pupils were his family. His very chair serves as a support to his present successor while he writes this article; it is not perhaps as inspiring as that of Joseph Black, which stands opposite it, but it is certainly more comfortable. His portrait, from a painting by Raeburn, is shown in figure 1. When George IV visited Edinburgh in 1822, the patriotic fervour of the Scots induced such a run upon representations of his royal figure that engravings of this picture, with the sash of the Order of the Garter across the chest as the sole alteration, were utilized to fill the local deficiency. These 'false Hopes,' according to information received some years ago from Sir James Walker, are now very scarce and command a high price. History does not disclose who was the more flattered by the incident—Hope or George IV!

Long after the latter's reign was ended, however, his scientific double continued his chemical activities. Hope delivered his last series of lectures in 1843. In the spring of the same year, at the age of 77, he blossomed out anew as a research worker in three communications to the Royal Society of Edinburgh, of which body he was then a vice-president. Two of these [3] [4] dealt with the constitution of the colouring matters in the leaves and flowers of plants, the third [5] discussed the temperature phenomena of the famous freezing cavern at Orenburg. With the coming of autumn, Hope's health deteriorated; he passed away on 13th June, 1844. His friend Dalton died only a few weeks later.

FIGURE 2 – *Hope's original preparation of strontium hydroxide.*

One human touch, for which I am indebted to my teacher and colleague Dr J. E. Mackenzie [7], may be added to conclude this memoir. During one of Hope's lectures, an unruly student threw a handful of peas at the professor and some struck him in the face. He started to reprimand the offender in dignified language, but suddenly lapsed into broad Scots as follows: 'Such conduct is unbecoming of a gentleman and moreover — it's daumed sair!'

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Book reviews

ROTATION OF THE GALAXY

Stellar Dynamics and Galactic Rotation, *by S. W. Shiveshwarkar. Pp. iv + 171. Lucknow University Studies No. xvi.* 1943.

Stellar dynamics is concerned with the spatial and velocity distribution of the stars in a system at every point of space and time. The methods are necessarily statistical, as it is not required to trace the motion of the individual stars. The study of steapy states of stellar systems is of particular interest. Though there is a close analogy between a stellar system and a gas, there is the important difference that close passages or collisions between stars are rare, whilst the molecules in a gas are in frequent collision. In a stellar system the law of attraction between individual members of the system is known to be the inverse square law. The pioneer investigations of Jeans, Eddington, and Charlier established a number of results of wide generality. The application of the methods of stellar dynamics to the rotating Galaxy is of interest, and enables some conclusions about the distribution of matter in the Galaxy to be derived. The phenomena of star streaming and of the asymmetrical drift of the high-velocity stars are both accounted for, but there is a discordance of some 20° between the observed and the theoretical directions of the star streaming. Shiveshwarkar shows that this may be explained on the assumption of a galactic expansion; but this is not necessarily the true explanation, and it has been criticized by Lindblad and others. Motions along spiral arms, as in a spiral nebula, may be involved.

This little volume provides an excellent concise summary of the main results in this field. Full bibliographical references are given. The volume is well printed and the type is clear.

H. SPENCER JONES

THEORY AND PRACTICE OF OPTICAL GLASSWORKING

Optical Workshop Principles, *by Charles Dévé, translated by T. L. Tippall. Pp. xiv + 306. Adam Hilger Limited, London.* 1943. 20*s. net.*

Messrs. Adam Hilger and the translator have performed a useful service to English-speaking opticians by the publication of this book, which was not well known in this country, although the original French text was published from the *Institut d'Optique* in Paris in 1936. It embodies much original discussion of the theory of optical grinding processes, and is the only treatment known to the writer in which the kinematical aspect of the subject is adequately considered. Its perusal cannot fail to be helpful to those who wish to short-circuit, or improve upon, the necessity for a long period of learning by example rather than precept.

The translation is, for the most part, happy, and few difficulties arise; but there are a number of passages in which, even in the original text, the argument is too condensed, and the present writer found it necessary to read certain passages several times before the meaning became clear, partly, perhaps, because the translator has adhered too closely to a rigid translation. For example, a sentence on p. 116 begins: 'The most general movement of a disc which is displaced on a stationary plate, guiding it by a central knob, is . . ., etc.' Now the meaning is clear enough on analysis, though the grammar is questionable; but the language might have been chosen to convey the meaning in a more vivid fashion. If the translator had spoken of 'a disc which, guided by a central knob, is sliding upon a stationary plate,' he would have caused no difficulty. A little later we are told 'The curve of rolling increases,' but cannot tell without analysis whether this refers to curvature in the mathematical sense or to radius of curvature.

It is not, of course, to be expected that this book will reflect details of technique which have been introduced during the present war, but if a good basic text is desired, it will go a long way towards meeting the need.

L. C. MARTIN

DICTIONARY OF ORGANIC COMPOUNDS

Dictionary of Organic Compounds, Volumes II and III, *edited by I. M. Heilbron and H. M. Bunbury. Pp. viii + 891 and viii + 977. Eyre & Spottiswoode Limited, London. New, revised, and enlarged edition,* 1943. £6 6*s. net each volume.*

War conditions have prevented the comprehensive revision of Volumes II and III of this Dictionary on the same lines as Volume I (reviewed in ENDEAVOUR, 3, 43), and these two volumes have been reprinted unchanged but with the addition of Supplements. These comprise 42 and 32 pages respectively. They deal mainly with recently investigated natural products (particularly alkaloids), polynuclear aromatic derivatives, and heterocyclic compounds, together with many cross-references to the other volumes. Literature references in these supplements cover the period up to 1942, but quite a number of compounds appearing therein carry references only prior to 1920. These, presumably, represent omissions from the first edition.

The task of bringing these volumes up to date must have been a difficult one under present conditions, and the collation of recent literature references thus made available is extremely valuable to all organic chemists. In view of the relatively small content of the supplements, however, it would have been a great advantage to those who already possess the earlier edition if these supplements could also have been published separately, pending the more comprehensive revision of the Dictionary as a whole which should become possible with the return of normal conditions.

J. W. BAKER

METALLURGY FOR THE MILLION

Metals in the Service of Man, *by William Alexander and Arthur Street. (A Pelican Book.) Pp.* 192. *Penguin Books Limited, Harmondsworth and New York.* 1944. 9*d. net.*

The beginnings of the art of extracting and working metals are lost in the mists of antiquity, yet the light alloy industry is of very recent origin and has opened up great new fields of usefulness. The marvellous way in which the properties of metals can be modified by the addition of proper alloying elements is among the outstanding achievements of modern times. The authors hope that this book 'will be of interest to the many who handle metals in their daily work, and perhaps also to those whose closest acquaintance with them is the keys of a typewriter or the parts of a rifle.' Although it is not intended to be a profound contribution to the literature of metallurgy, the authors have not hesitated to include discussions of scientific advances where these are of real importance in the use of metals. For example, the development of X-ray methods of structure analysis has provided metallurgists with their most

powerful tool for the investigation of the metallic state. This fascinating volume deserves a wide public, for the writers have succeeded in presenting the accomplishments of a great industry with sound scholarship, enthusiasm, and charm. W. WARDLAW

ULTRA-FINE STRUCTURE OF COALS AND COKES

Proceedings of a Conference on the Ultra-fine Structure of Coals and Cokes, held at the Royal Institution, London, 24th–25th June, 1943, *by the British Coal Utilization Research Association. Pp.* 366. *H. K. Lewis & Company Limited, London.* 1944. 25*s. net.*

Sir Evan Williams, in the foreword to the *Proceedings*, suggests that we are entering upon an era in which great industries based on the use of coal as a chemical raw material may be developed. Such a view stresses the importance of long-range and fundamental investigations into the properties of coal and the utilization of coal resources. Therefore, in order to ensure success, two different groups of people were invited to the conference, viz. those concerned with the production and use of coal on the one hand, and scientists from the universities and technical colleges on the other. It is agreed that the Conference represented a bold experiment, because the problems chosen were difficult, and the majority of the twenty-two papers presented dealt with fundamental work on some aspects of structure such as, for example, the colloidal and internal structure of coal.

X-ray diffraction technique and the electron microscope were both called upon to help, while the infra-red spectrum, and optical, magnetic, and electrical properties, were among the other angles of attack.

In most cases the papers are followed by a bibliography and details of the discussion. In addition to author and subject indexes, there are some 119 figures, mostly graphs, about 70 tables of data, and 14 full-page plates excellently reproduced, the whole constituting a volume which all interested in the utilization of coal should peruse with care. ARTHUR MARSDEN

THE CHEMISTRY OF HORSE-DOPING

Notas Microquímicas sobre 'Doping,' *by Dr. Enrique Herrero Ducloux. Pp.* 265. *Peuser Lda, Buenos Aires.* 1943.

Some years ago, the racing committee of the Buenos Aires Jockey Club appointed a group of experts—chemists, physicists and veterinary surgeons—with a jurist as president, to provide a scientific basis for a system of control over horses entered for racing events. In that connexion, the author investigated methods of detecting 'dopes,' and this book records his results.

He confines attention to the formation of crystalline precipitates of derivatives of the drugs used, provides descriptions of reagents found useful, with notes on the concentrations at which they are effective, and gives nearly 200 excellent microphotographs of crystalline preparations yielded by the thirty-eight drugs selected. For confirmatory tests, such as the usual colour reactions, he refers the reader to the bibliography of toxicological text-books provided, but includes a short descriptive monograph on each drug.

A 'dope' is defined as 'any chemical or physico-chemical agent administered before the event to a racing animal with the object of influencing its locomotive power and eventually its speed.'

The range of drugs dealt with is evidence of the ingenuity and up-to-date pharmacological knowledge of the purveyor of 'dopes.' Not only are the expected stimulants, sedatives, and poisons included, but also substances influencing glandular secretion and body temperature, and harmless materials, such as urea, intended to mislead the chemical investigator.

T. A. HENRY

STANDARD BIOLOGICAL PREPARATIONS

Biological Standardization, VI (Bulletin of Health Organization). *Pp.* 80. *Allen & Unwin Limited* (*League of Nations Publications Department*), *London.* 1942–43. 4*s.*

The League of Nations still survives, and its Health Organization has now published another number of its Bulletin. The international co-operation in this field has proved probably the most lasting and the happiest of all, and to medical science it has been of great value. Biological standardization, involving as it does agreement about standards and units of measurement of therapeutic agents, is an obligatory interest for all countries, and on its account many co-operative investigations have been arranged and completed.

The Bulletin just issued deals in the main with the replacement of the standard preparations collected by international agreement before the war, and now becoming exhausted. For extract of the posterior lobe of the pituitary gland, for example, there has been a stock of dried posterior lobe kept at the National Institute for Medical Research at Hampstead, for distribution to workers in any part of the world on demand, to be used as a standard with which to compare in potency freshly made samples. The replacement of the stock as it becomes exhausted involves much labour, for the new standard is distributed to a great many workers to get their opinion of the relation between the new and the old standards. By taking an arbitrary mean of these opinions the relation is established. This kind of work has been done for many substances: for the standards for the oestrus-producing hormone, for male hormones, for the progestational hormone of the corpus luteum, and others. The Bulletin also contains an account of work on standard preparations of the three gas gangrene antitoxins and of heparin. On account of this work, great progress throughout the world in the development of therapeutic substances has been made possible.

TREATMENT OF NEMATODES IN LAMBS

Co-ordinated Trials with Phenothiazine against Nematodes in Lambs. *Imperial Agricultural Bureaux, Joint Pub. No.* 4. *Agricultural Research Council of the United Kingdom, London.* 1943. 3*s.* 6*d.*

This report is interesting not only for the results obtained but also for the methods which were used. The experiments were planned so that statistical procedures could be applied to the results obtained at a number of different centres, and the report contains an account of two new developments of existing statistical procedures. Evidence from inside flocks indicated that the greatest relative reduction in egg-count was caused by the lowest (5 gr.) dose used. Evidence from outside flocks was that, while egg-count reductions had been obliterated by reinfestation (except in flocks grazed on clean pasture), there was a relatively large weight response in the treated lambs, which increased roughly in proportion to dosage up to the highest dosage used (50 gr.). From these results it is suggested that the action of phenothiazine may lead to a reduction not only of stomach worms but also of certain intestinal worms usually considered of little clinical importance.

Notes on contributors

DAVID BRUNT,
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Was born in Montgomeryshire in 1886, and was educated at the University College of Wales (Aberystwyth) and at Trinity College, Cambridge. He was elected Isaac Newton Student in the University of Cambridge for research in astronomy, and afterwards became lecturer in mathematics in the University of Birmingham (1913–14) and the Monmouthshire Training College, Caerleon (1914–15). During the war of 1914–18, he served in France in the Meteorological Section of the Royal Engineers, and for the last twelve months was Meteorologist to the Independent Air Force (mention in despatches). For fifteen years after the war he was Superintendent of the Army Services Division of the Meteorological Office, and since 1934 has been Professor of Meteorology at the Imperial College of Science and Technology, London—the only institution in the British Empire to have a chair of this subject. He is interested in gardening, motoring, and gliding. He has been President of the Royal Meteorological Society since 1942, and has served on the councils of the Royal Society, the Royal Astronomical Society, and the Physical Society. Though at present nominally working at Imperial College, he is actually much occupied with many war problems.

W. T. ASTBURY,
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Is a leading expert on textile physics, specializing particularly in the structure of proteins and of natural and artificial fibres. Born at Longton, Stoke-on-Trent, in 1898, he was educated at Longton High School and Jesus College, Cambridge, afterwards becoming assistant to Sir William Bragg at University College, London, and the Royal Institution. In 1928 he was appointed lecturer in Textile Physics in the University of Leeds, where his brilliant researches earned him a Medal from the University of Lille, the Gold Medal of the Company of Dyers, and the Warner Memorial Medal of the Textile Institute. He finds his principal relaxation in music.

J. YULE BOGUE,
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Was born in 1905 and was educated at Blundell's School, Tiverton, Glasgow Veterinary College, and the University of Edinburgh. He carried out physiological research work at the Universities of Edinburgh, Berlin, London, Harvard, and Oxford, and in 1933 was appointed lecturer in physiology at the Royal Veterinary College, London, subsequently (1939) succeeding to the chair of physiology there. In 1943 he resigned his professorial post in order to take up an appointment as physiologist with Imperial Chemical Industries. His field of research covers electrical responses of tissues and cardiac metabolism. He is particularly interested in the application of physical methods to the solution of physiological problems. He was elected first President of the Association for Scientific Photography in 1943, and has made a special study of the production and distribution of scientific films for teaching purposes. Among his other interests are travel, flying, and winter sports.

DENNIS FRY, *B.A.*,

Studied phonetics in the Phonetics Department of University College, London, under Professor Daniel Jones. He was appointed to the staff of the Department in 1934, and three years later was placed in charge of the University College Phonetics Laboratory. Since 1939 he has been occupied in research for the Royal Air Force into problems connected with the transmission and reception of speech signals.

J. Z. YOUNG,
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Was born in 1907 and was educated at Marlborough College and the University of Oxford. Specializing in zoology, he worked for two years at the Marine Biological Station at Naples, afterwards returning to Oxford, where he is now Fellow of Magdalen College and University Demonstrator in Zoology. His research work has been on the microscopic structure and function of various tissues, especially in the nervous system. During 1936 he held a Fellowship of the Rockefeller Foundation and worked at Chicago and Woods Hole, Mass. Before the war he was experimenting with the higher nervous centres of squids and similar animals in an attempt to throw light on the mechanism of learning. Since 1939 he has been conducting research on methods of treating injuries of the peripheral nerves. He is a member of the Nerves Injuries Committee of the Medical Research Council, and during 1943 visited the United States for consultation with American workers in this field.

JAMES SMALL,
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Has been James Watt Professor of the Theory and Practice of Heat Engines in the University of Glasgow since 1938. He served his apprenticeship to mechanical engineering with Barr and Stroud Limited—well known as makers of range-finders and other precision instruments—and studied engineering at the University of Glasgow. He later specialized in the field of applied thermodynamics and heat engines, becoming (1921) chief assistant to Professor W. J. Goudie, the authority on steam turbines, whom he later succeeded. He has done much research work and published many papers on internal combustion, on heat transmission, and on analogous problems of diffusion. The subject of refrigeration falls within the scope of his chair, and to it he has given much attention.

JAMES KENDALL,
M.A., D.Sc., F.R.S.,

Is Professor of Chemistry in the University of Edinburgh and thus occupies the chair once held by Thomas Charles Hope, the subject of his article in the present issue. Like Hope and not a few others, he has discovered that the teaching and administrative responsibilities of a large department are incompatible with intensive original research, and has accordingly concentrated mainly upon his duty of 'communicating a knowledge of chemistry to the rising generation.' He was educated at Farnham Grammar School, the University of Edinburgh, and the Nobel Institute, Stockholm. From 1913–26 he held a chair of chemistry in Columbia University, New York, and later was Professor of Chemistry in Washington Square College, New York University. During the first world war he served in the United States Naval Reserve.

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